European Commission

Proceedings of the 6th International Conference EEDAL'11 Energy Efficiency in Domestic Appliances and Lighting

Gueorgui Trenev
Paolo Bertoldi

JOINT RESEARCH CENTRE

2013

Report EUR 26492 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Paolo Bertoldi
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 450, 21027 Ispra (VA), Italy
E-mail: paolo.bertoldi@ec.europa.eu
Tel.: +39 0332 78 9299
Fax: +39 0332 78 9992
www.jrc.ec.europa.eu
http://re.jrc.ec.europa.eu/energyefficiency/

JRC 87434

EUR 26492 EN

ISBN 978-92-79-35418-2 (pdf)

ISSN 1831-9424 (online)

doi: 10.2790/14411

Luxembourg: Publications Office of the European Union, 2013

Printed in Italy

Proceedings of the 6th International Conference EEDAL'11 Energy Efficiency in Domestic Appliances and Lighting

Gueorgui Trenev

Paolo Bertoldi

JOINT RESEARCH CENTRE

Contents

Policy

Programmes

Standards and Labels

MEPS (Standards)

Labelling

Smart Meters

Behaviour

INTRODUCTION

The 6th EEDAL Conference was organised by the European Commission JRC and the Danish Energy Association, the association of the Danish electricity companies, and took place on 24 to 26 May 2011 in Copenhagen.

EEDAL is an established international conference in which experts for energy efficiency from the ministries, industry, science and associations meet every two years to discuss the latest development in policy and technologies related to residential appliances, equipment, lighting and consumer behaviour. EEDAL covers both technologies and policies and programmes.. The perspective is global and the participants come from all over the world. This important international event provides a unique forum to share both knowledge and experiences.

Over 250 participants attended the EEDAL conference, with participants from most of the EU member states, US, Canada, China, Japan, South Africa, South Korea, India, Brazil, etc. 136 peer reviewed papers were presented in scientific sessions covering the different technologies and programmes. In the 2011 many presentations covered smart meters and smart appliances as part of the smart grid.

The EEDAL opening session was chaired by Dr.Giovanni de Santi, Director for the JRC Institute for Energy and Transport, acting as the conference general chairman.

The first plenary speech was by Ms. Lena Ek, Member of the European Parliament. Ms Ek stressed the importance of energy efficiency in meeting the EU 2020 targets, and the large benefits for citizen deriving by energy efficiency.

Mr Dominique Ristori, Director General of the JRC, highlighted the importance of energy efficiency in meeting the EU energy policies, the contribution to the 2020 flagship initiatives, and he highlighted the role of innovation to identify and bring to the market new and innovative solutions to further improve energy efficiency.

Mr. Rick Duke, US Department of Energy, Deputy Assistant Secretary for Climate Policy, presented the US energy efficiency policies, and in particular the importance of energy efficiency in residential appliances. He also presented the SEAD initiative for super-efficient appliances under the Clean Energy Ministerial.

Ms Friis, Danish Minister for Climate and Energy and Minister for Gender Equality, presented the Danish plan for a fossil fuel free economy in Denmark by 2050. Renewable energies together with energy efficiency will be the key component of this strategy.

Mr. Bo Diczfalusy, Director of the Directorate of Sustainable Energy Policy, presented the IEA activities on energy efficiency. He presented the IEA 25 recommendations on energy efficiency policies to governments in the frame of the G8 activities. Also the IEA has highlighted the role of energy efficiency in a low carbon future

Mr. Jacek Truszczynski of DG ENER presented the latest Commission activity on energy efficiency including the Energy Efficiency plan, the Eco-design and energy labelling

The final presentation of the opening sessions was by Sandeep Garg, Energy Economist at the Bureau of Energy Efficiency Ministry of Power, India. Nowadays India has a quite comprehensive set of legislation on energy efficiency, though the major problem is the enforcement of the legislation.

EEDAL 2011 was very successful in terms of quality of participants, level of presentation, and satisfaction of the participants.

Co-operative Concept for Providing Energy Efficiency Services - Pilot Field Study

Virve Rouhiainen

Adato Energia Oy

Abstract

This paper presents the first experiences from a pilot study in which a co-operative concept for providing energy efficiency services for households is tested in the field. The concept consists of a toolkit (which is used to identify and plan the needed actions in households) and the creation of a network (which will provide the commercial services). In addition, a network providing support for problem-solving is created.

The partners in the concept are a local utility, a local energy efficiency office and a national information and tool provider. The original idea was to educate a group of volunteers (10-15) to make an energy-saving plan for a group of individual households (75-100) using printed material and a web tool. Despite an extensive recruitment effort only 21 people volunteered. They turned out to have low electricity consumption in comparison with their reference households. In response to this, the project focus was shifted on finding ways to help the participants to tell others on their practises. From other studies we know that the majority knows very little of energy consumption and we expect that peers are more likely to be successful in this kind of communication.

The project has two aims. The first is gathering feedback of how useful the existing materials and tools are in practice. The second is to find out how well peer groups function in practice, what kind of problems will occur and whether these can be tackled with the planned network. If the concept is viable it can easily be extended and adapted to varying circumstances in other parts of the country.

Introduction

In Finland, only some requirements of the Energy Services Directive are implemented by state legislation. Among these is the requirement of article 13 paragraph 3 [1], which is implemented in Finnish law in the form that energy sales companies are to provide their final customers an annual report on energy consumption [2]. Generally, the requirements of the directive are carried out using voluntary energy efficiency agreements [3]. For example, electricity companies can participate in two action programmes: one on improving generation efficiency (of which there are currently 33 participating companies [4]) and one on improving energy services (in which 85 companies currently participate [5]). The action plan for energy services includes a commitment to provide and improve energy efficiency services to their customers.

In spirit of this commitment, the industry has carried out a number of actions. Some, like the guide on household customer electricity consumption report [6], have been carried out in co-operation with the authorities. Some, like the Elvari program [7], involve only a few of the companies. Some, like this project, are part of a larger effort the industry is making to face the challenge of climate change and becoming a part of the solution.

A recent survey commissioned by the Elvari project [8] showed that 68% of the households did not know their electricity consumption in kWh. Little over half (57%) knew their consumption in Euros. Whether the customer had received a report on energy consumption from their electricity provider did not seem to affect the result.

The household customer electricity reports were tested in three customer panels. The discussions showed that the customers were not familiar with the reports even though their electricity provider had sent them to them for years. Furthermore, some of the ideas the customers suggested, like net calculators, have been available for 15 years. Clearly, the information provided has not reached the customers.

The project has two goals. The first goal is to get feedback from customers on the present set of tools and to gather ideas on how to develop them further. This is especially important now when new technology offers large scope for new interventions and we need to evaluate which are the best options to carry out.

The second goal is to see if energy efficiency awareness can be increased with this concept of educating volunteers, who in turn spread the knowledge further. The tools are designed so that we also hope to see concrete energy savings, which we will try to quantify via measurement.

The project is designed so that it fits the planned model for providing energy efficiency information in Finland [9]. If successful, the model can easily be used elsewhere in the country and abroad.

The paper is organised as follows: First the project is described in general. Then materials used in the project are described. Thereafter the project plan is described in more detail. This is followed by a discussion and paper ends with preliminary conclusions.

General organization of the project

Project parties and project group

The partners in this concept are the local utility Turku Energia, local energy efficiency office Service Centre for Sustainable Development and Energy of Southwest Finland (Valonia), and national information and tool provider Adato Energia Oy.

Adato Energia Oy works at the source of energy information. It produces different services for Finnish energy companies. It was founded by the energy industry to produce information and to gather knowledge on current events. Its customers comprise energy companies, electricity and district heating companies, and network construction companies. Adato Energia Oy is owned by the Finnish Energy Industries, the trade association representing the Finnish energy industry. See www.energia.fi/EN and www.adato.fi.

Turku Energia is the leading power supplier in Southwest Finland. The company's operations are based on competitive energy prices, competent personnel, service reliability, profitability and environmentally-friendly processes. Its core business consists of procurement, distribution and the sale of electricity and heat, as well as development, construction and maintenance of power plants and distribution networks. Turku Energia's customer base consists of private consumers, companies and communities. See www.turkuenergia.fi

Valonia is an energy efficiency office operating in Southwest Finland. Annually, it organises a number of campaigns on sustainable development and offers educational services. These include courses for energy experts [10]. The office is part of the organisation of the city of Turku, which with 176,000 inhabitants is among the largest cities in Finland. See www.valonia.fi.

Turku Energia and Valonia have long experience in carrying out projects in co-operation and this is why they were asked to become parties of this pilot study.

The project team has four members: Virve Rouhiainen (Adato Energia), Päivi Rae and Mikko Merisaari (Turku Energia) and Liisa Harjula (Valonia). Finnish Energy Industries, Turku Energia, Adato Energia and Sähköturvallisuuden edistämiskeskus, fund the project.

Overall project plan

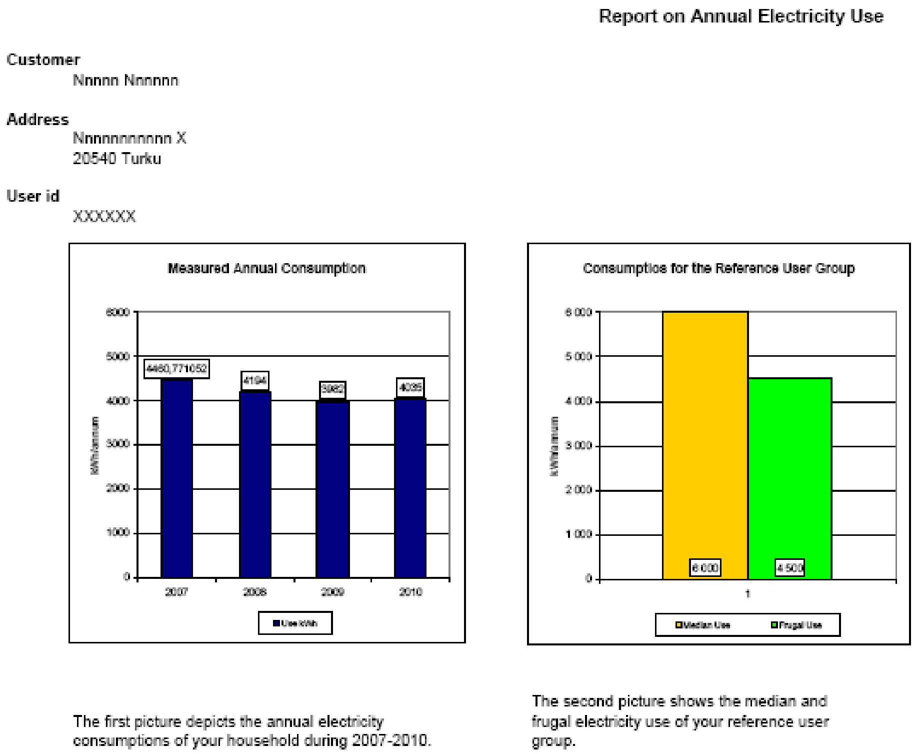
A project can be described in number of ways. We distinguish between ongoing processes and project phases. Processes include the planning project phases, project administration, internal and external communication and maintaining support functions. The project phases include recruiting the participants, coaching the group leaders, creating the support organisation, creating the saving plans for participants, implementing the saving plans, collecting the project results, organising the concluding event for getting feedback and rewarding participants and writing the report. These are described in more detail below.

Information and tools used to set and achieve the targets

Evaluation of the starting position

To give households their starting position, we adapted the more developed of the two reporting formats suggested in the report, “Sähkönmyyjän raportti asiakkaan energiankäytöstä” [6]. In addition to reporting formats, this report specifies reference-user categories and the size of average and frugal levels of electricity use for each household category. Thus each participant got an idea of how his/her consumption relates to other consumers. Figure 1 gives an example of the reports provided.

Figure 1. Example of the starting point report provided for the participants



In the customer panels where the report formats were tested, these reference user categories raised a number of questions. The internet tool Sähkötohtori is able to provide an answer to number of these questions and thus the next step is performing this analysis. (See http://www2.energia.fi/sahkotohtori/). This tool breaks down the annual electricity consumption into appliance components and gives the normal range of consumption on each component as well.

This tool is built to describe the variation of electricity use in households. Table 1 shows the Sähkötohtori analysis results of the project participants without electric heating. It is worth to note that both the absolute numbers and the consumption shares vary considerably. No wonder consumers ask for tailored information [6].

Sähkötohtori is built and calibrated using the data of Kotitalouksien sähkönkäyttö 2006 study [11]. The measured consumptions in this study vary a lot. Similar variation has been found in earlier Finnish studies as well as number of other studies e.g. that of Swedish energy agency. (See http://www. energimyndigheten.se/Global/Energifakta/Förbättrad%20energistatistik/ Festis/ Final_report.pdf.)

Table 1. The Results of Sähkötohtori Analysis of Participants without electric heating

Total annual consumption kWh	1601	1724	2619	3145	5701	6499	7695	8548
Car heaters					28	31	134	168
Cold appliances	396	800	400	400	1934	374	1552	720
Cooking	172	357	335	453	267	377	308	463
Dishwasher	85		90	30		56	260	195
Home electronics	174	194	100	699	465	1290	1530	341
Laundry	47		110	37	31	68	73	73
Lighting	309	203	348	476	2347	988	2400	2400
Other consumption	33	170	170	300	42	47	450	450
Sauna stove	125		216				288	288
Secondary heating and heating equipment	260		850	750	587	3268	700	3450
Consumption Shares	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Car heaters	0 %	0 %	0 %	0 %	0 %	0 %	2 %	2 %
Cold appliances	25 %	46 %	15 %	13 %	34 %	6 %	20 %	8 %
Cooking	11 %	21 %	13 %	14 %	5 %	6 %	4 %	5 %
Dishwasher	5 %	0 %	3 %	1 %	0 %	1 %	3 %	2 %
Home electronics	11 %	11 %	4 %	22 %	8 %	20 %	20 %	4 %
Laundry	3 %	0 %	4 %	1 %	1 %	1 %	1 %	1 %
Lighting	19 %	12 %	13 %	15 %	41 %	15 %	31 %	28 %
Other consumption	2 %	10 %	6 %	10 %	1 %	1 %	6 %	5 %
Sauna stove	8 %	0 %	8 %	0 %	0 %	0 %	4 %	3 %
Secondary heating and heating equipment	16 %	0 %	32 %	24 %	10 %	50 %	9 %	40 %

Setting saving targets

When setting saving targets the first thing to consider is the level of electricity consumption in the household. If the electricity consumption is low to start with, it is unrealistic to set a large reduction target. The largest household group in Finland (25% in 2009) is singles living in a flat [12]. For that group the first quartile for annual consumption is 1090 kWh, the second quartile is 1500 kWh and the third quartile is 2160 kWh[1]. An already-frugal household will thus struggle to achieve high saving targets, as all the low - hanging fruit would have been implemented already. A household in the last quartile should have various options - both behaviourally and technologically - of how to significantly reduce their consumption.

Further actions to reduce consumption vary in terms of required effort and cost. If the reason for high consumption is an old fridge, replacing it will involve the cost of buying a new one - something the household may not be able to afford. Some actions on the other hand are cheap to carry out. For instance, turning off the computer when it is not being used may well decrease the consumption by 700 kWh p.a. with no monetary cost involved[2].

1 In Finland, practically all flats have central heating which includes warm water. The most common energy source for central heating in flats is district heat with a 90% share. The second most common is fuel oil with a 5% share.

2 One participant metering the electricity consumption of her computer in Kotitalouksien sähkönkäyttö 2006 study, was able to achieve this annualised saving just by turning off her computer when it was not used. The computer was metered before and after the change in behaviour. This result was published in a newspaper

The analysis of Sähkötohtori will be used as the starting point to set saving targets. To help identify possible actions, the participants will receive a self audit form (available in Finnish here http://www.motiva.fi/julkaisut/ koti_ja_asuminen/ tutki_pientalosi_energiankaytto_tee_se_itse_-kotikatselmus.1046.shtml). They can then themselves decide what actions they wish to take. These will be recorded on a form and collected back. Some of the actions suggested in the audit may be such that households find them difficult to perform and this information will be recorded as well. For some actions, instructions that are more detailed are available but new information needs and solutions for providing them will be identified, where possible.

Feedback during saving

Earlier research shows that continuous feedback is important in achieving targets and, preferably, that feedback should be broken down to appliance categories [13]. Though it is possible to breakdown the load-to-appliance components, no reliable model calibrated to Finnish data exists today and this will therefore not be attempted.

Those participants having[3] are required to have hourly electricity metering and they will be provided with a monthly report on their electricity consumption which will be related to their individual target savings. In case the savings do not materialise, the hourly consumption will be looked into in more detail.

Carrying it out

Recruiting the volunteers

The original plan was to have volunteers and their groups come from the same organisation e.g. a neighbourhood association. Thus, the participants would know each other from the start and less time and effort would be needed in getting to know each other. Further, if they came from the same organisation, competition between groups might develop more easily.

First we tried to recruit the volunteers by contacting suitable organisations and entities like the homeowners' association. This recruiting effort was supported by placing information on the websites of Turku Energia and Valonia. It soon became obvious that this alternative was not viable as we only got three volunteers from this approach. So we decided to use another approach to recruiting. This consisted of sending a letter to 400 households (on January 11, 2011) having an hourly electricity meter and supporting the recruitment effort by local media coverage. Turun Sanomat, the leading local newspaper, published an article on January 14, 2011 and the project was mentioned in two broadcasts in week 3.

Recruiting the volunteers turned out harder than we had thought. By January 19th we had recruited 21 volunteers and we decided to carry on and revise the plan to suit the smaller number of volunteers. The main revision was that the coaching would be held for all participants and thus the role of the group leaders would become of lesser importance. Table 1 shows the channels through which the volunteers were recruited.

Table 1. Number of Volunteers Recruited via Channels Used

Recruiting via Massmedia		**Recruiting via Individual Contact**	
Channel	**Number of volunteers**	**Channel**	**Number of volunteers**
Newspaper article in Turun Sanomat	5	E-mail to association members	5
Newspaper article in Turku Posti	1	Personal letter from Turku Energia	2
Newspaper article in Turkulainen	1	E-mail to energy experts in Turku area	1
Story in local radio (Turun radio)	1	Leaflet delivered to mailbox	1
Ad in Turku Energia's customer Magazine	1		

article (Laitinen, Helsingin Sanomat Jan 30, 2008). The trial was carried out to provide a concrete example of savings possible for the newspaper. This single trial was not included in the project report, because the empirical establishing of savings was outside project scope.

3 Original plan was to require all participants to have hourly metering, but this requirement was abandoned.

Story in Homeowner's associations leaflet	1		
Ad in Turku Energia's webpage	1		
Ad in Valonia's webpage	1		
Ad in the webpage of city of Turku	0		

Organising coaching and proceeding to create saving plans

The plan for coaching included three occasions. The first occasion was a get-together on Jan 26, 2011 in the premises of Valonia in the city centre. The participants met each other and the project team. The purpose of this meeting was to boost spirits and to give the project team further information on participants. Liisa Harjula of Valonia has trained energy experts [10,14] and this meeting was her suggestion. Why she suggested it became evident in the meeting where the participants vented their feelings about the electricity market. If the message is to be summarised in one sentence it is "Asking us to save electricity ain't fair".

It is interesting to note that a recent study [15] analysing energy conservation communication in Finland formulates the problem as follows:

> *"Analysis of the combined data showed that much of the energy conservation communication is aimed at improved customer relationship-building, while the effectiveness of energy communication is undermined by a deadlock of factors that reinforce each other, e.g. consumer lack of energy market understanding, resulting lack of interest and lack of timely feedback to households. Thus, in order to make household consumption more sustainable all the barriers should be addressed …"*

The first stumbling block we encountered was the general negative feeling about the electricity market. Information on energy efficiency alone is simply not enough - something that became obvious to the project group after the first meeting night.

The first coaching evening took place on Feb 15th and the second on Feb 22th. The venue was Turku Energia. Both occasions consisted of a lecture and group work. The planned focus of the first night was the size of household electricity consumption and how it varies and why. In addition to this we explained the structure of the electricity bill and why it is as complicated as it is. The participants were provided the starting point report and they did the analysis with Sähkötohtori. Unfortunately, we ran out of time before the participants were able discuss the differences in their consumption. As homework, the participants were to perform the self audit and to think how to save electricity in ones own home. In addition, they were to underline the actions they would not know how to perform and mark the actions they did not understand with question marks.

Turku Energia had not yet provided its customers with these reports and the participants told us that it was really interesting to find out about the consumption of others. The analysis of the first evening results showed that our project participants belonged to the frugal segment of their reference groups. (See table 3). This is why we decided to focus on the second evening more on how to pass their knowledge on than how to make a detailed saving plan. In addition to that, each participant was to decide on one or two actions they would carry out at home.

The second night's lecture was about energy saving actions. Then the participants were divided into three groups on basis of their housing type and heating fuel. The groups were flats and row houses (4 participants), electrically-heated houses (5) and other houses (3)[4]. The participants were given three themes: to discuss what they had already done and what they still could do, to give feedback on the do-it-yourself audit and to make suggestions to improve energy efficiency information. Further, each participant made a promise what they themselves would do.

The analysis of the returned audit forms suggested that the audit itself was easy enough to understand. The group discussions were more critical. First, both non-electrical heating groups asked for an audit tailored to meet their situation. Second, some of the advice was considered too general. The groups made a number of suggestions how to improve the provision of energy efficiency information. Even tough

4 Some participants were unable to attend this evening because of school holidays

the participants had already taken a number of actions to save electricity, they were all able to come up with something they still could do.

Providing feedback and support

The coaching is followed by a three month period during which the participants carry out the energy saving actions. They receive feedback on two follow up meetings (March 30th and May 16th). In addition they were asked to recruit other people to try Sähkötohtori.

At this point it seems likely that no surprising consumption patterns will emerge. Thus the project group can service the role of the support organization for this project and other professionals are not needed. The idea of a support organisation stemmed from the utilities' long experience of providing energy audits and the authors' experience with measurement studies. Unexpected arrangements have been discovered when conducting audits. For instance, a new owner of a house with extremely high electric bills did not realise something was causing the disappearance of the snow from the yard during the winter.[5]

Further, clear evidence exists that households that are wondering why their electricity consumption is higher than their neighbours' tend to seize the opportunity of participating in measurement projects [11] and we needed to prepare for this. As table 3 shows, this is not what happened in this study. In fact, the participants in average have lower consumption than that of their respective reference groups.

In addition of showing the numbers for the participants, table 3 illustrates the difference between two interventions by comparing the participants of this study and a recent Finnish study piloting the use of internet based feedback system showing the total electricity consumption of household on varying time resolutions the smallest resolution being one minute. Most participants of the latter study were recruited from the utility personnel, so their knowledge is in all likelihood better than that of a typical consumer. Their consumption average none the less is slightly higher than the average of their reference group when the participants of this study on average use less electricity than their reference group.

Table 3. The analysis of the annual electricity consumption of participants of two Finnish pilot studies.

Heat 2007 data				**Data of this study**			
Participant code	**Observed annual consumption kWh**	**Annual median consumption of the reference group kWh**	**Reference group percentile**	**Participant code**	**Observed annual consumption kWh**	**Annual median consumption of the reference group kWh**	**Reference group percentile**
VES7	13 410	18 020	16 %	Os3	1 367	2 500	6 %
VES10	14 520	19 968	16 %	Os1	4 035	6 000	19 %
VES8	18 000	19 968	32 %	Os11	15 050	18 177	25 %
VES2	17 530	18 020	45 %	Os13	22 631	26 500	26 %
VES3	18 800	18 020	56 %	Os14	5 701	7 000	27 %
VES9	6 160	5 375	58 %	Os12	20 882	23 895	30 %
VES6	23 390	18 020	79 %	Os7	5 065	6 750	34 %
VES1	2 500	1 500	83 %	Os2	6 079	6 000	51 %
VES4	28 850	21 916	85 %	Os8	20 914	19 950	57 %
				Os9	7 623	6 000	65 %
				Os6	2 164	1 500	75 %
				Os4	2 472	1 500	82 %
Average	**15 907**	**15 645**	**52 %**		**9 499**	**10 481**	**42 %**

The first two columns of the Heat 2007 data are taken directly from the table of the report Kotien reaaliaikainen sähkönkulutuksen mittaaminen ja havainnollistaminen [16]. The reference group of the household is determined on basis of the provided information and corresponding numbers are taken from the report Sähkönmyyjän raportti asiakkaan energiankäytöstä [6].

5 This 'something' was an electric cable installed to keep paved pathways free of ice and snow. This technique is more commonly used for heating gutters and water piping, but it can also be installed under yard paving.

Given that the participants of this project in general have rather low electricity consumptions, they have performed a number of actions to save electricity and their feedback from the first evening it seems likely that this type intervention will appeal to those people already interested in energy saving.

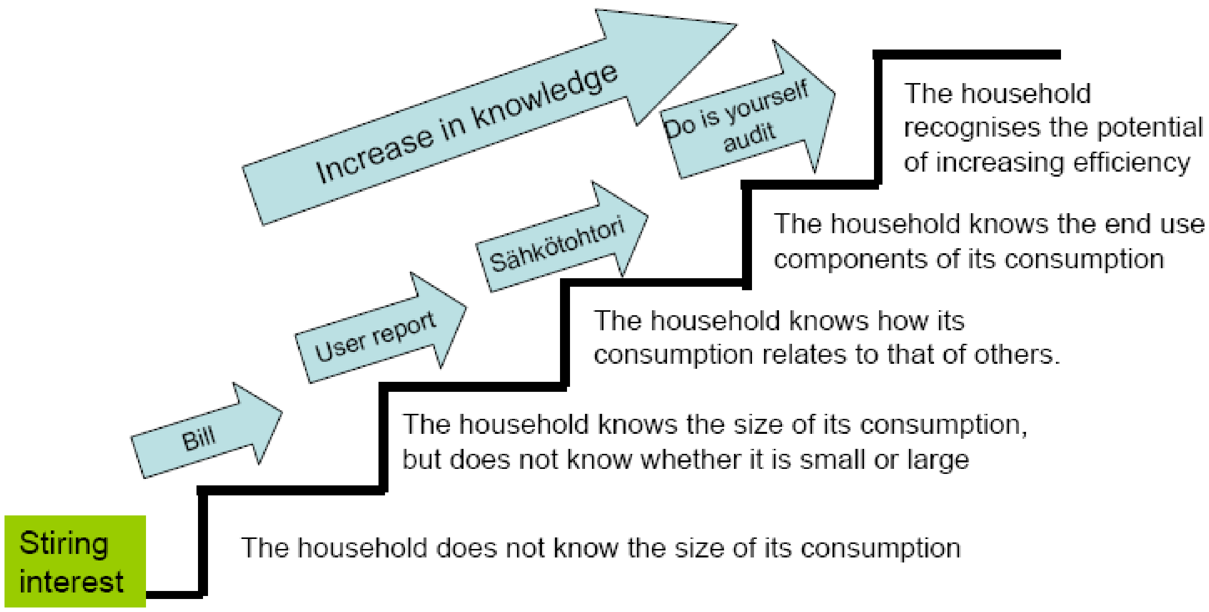
Evaluation and getting feedback

At the end of the project we will evaluate the results and collect feedback from the participants. The exact format will depend both on the number of participants and the clues we expect to find during the project. We will also reward the best idea(s) to develop the concept further and of course, we will reward the group with the best result.

Discussion

This paper describes the experiences from a pilot field trial. It is designed to fit to the planned Finnish Energy Advice system and it is utilizing the existing tools. These are combined so that they push the consumers on a higher level of knowledge. Figure 2 depicts the idea how consumer awareness of his or her electricity consumption increases and what is the source of information.

Figure 2. Household's Step of Increasing Knowledge



The first stumbling block the project encountered was in stirring interest. Lack of interest is obvious and the general negative feeling about the electricity market is in all likelihood part of the problem. The first evening was about venting the feelings and had it not been Liisa Harjula's earlier experience in educating volunteers this event had not been taken place. During the first meeting project team succeeded in answering the questions and in creating a positive atmosphere.

The questions of first evening were summarized and are now being used in educating utilities personnel in answering difficult questions. The first responses have been positive. People in customer service encounter these questions frequently. Interestingly Korsunova also identified this problem via interviews of the personnel of the utilities and she recommends "education on energy market system in general". This formulation is too general for practical purposes. The questions identified are used to start this work. They may not solve the whole problem, but they are a concrete starting point.

The second stumbling block needing attention is the electricity bill. During the first evening one participant stated that understanding the electricity bill was her main motivation to participate. In response this issue was added in the material of the first coaching night. The issue reappeared in the first follow up meeting. One of the participants complained that despite the training he still could not understand his bill. As he has hourly metering Turku Energia is able to offer him and other participants with hourly metering an alternative billing format. If the participants find this format an improvement, Turku Energia and the industry in general may well decide to speed up the transition to this billing format[6].

The analysis of the participants electricity consumptions indicates that this type of intervention will appeal to those people already interested in energy saving. This self selection bias also rendered the planned support function unnecessary in this project. With another type of intervention (like using a measurement system) appealing to higher than average users this function may well be necessary.

The use of designed experiments is the recommended approach to establishing the effects of interventions. However, the large variance of electricity use often results the difference between treatments being statistically insignificant [17]. For some reason, the connection between this large variance and the need for tailored information is not made, though these are in fact two sides of the same coin.

The planned quantification of saving results in this study rests on combining the results from Sähkötohtori with hourly measurement data, not on performing an analysis of variance. The reason for this decision is theoretical. Should the project succeed in its aim of making the participants pass the information on others, the assumption that the control group receives no treatment would be violated and the analysis would not make sense. An alternative of using non local control group was not appealing either. The underlying idea of making people to pass knowledge is simply incompatible with assumptions of designed experiments and thus another form of quantification is needed.

Conclusions

Following conclusions can be made at this point of the project:

Using a pilot study to test a new concept is useful because small scale study allows the needed flexibility to revise the project plan when problems occur. We needed to do that with respect to recruitment and we also needed to revise the original plan of how we could run the project as we were able to only recruit some 20 volunteers.

Academic literature seldom gives detailed advice on how to achieve things in practice. Liisa’s experience in designing the coaching probably helped us to avoid catastrophe. The questions of the first night will help us to start “education on electricity market system in general”, as suggested by Korsunova.

Feedback on the tested material enforces the earlier message from customers: Information needs to be tailored to meet the customer circumstances, the more personal the better. The tool used is designed to give tailored advice. The need for tailored advice probably stems from the large population standard deviation of electricity use[7].

The type of self selection bias may depend on the type of intervention tried. The comparison of the data on the participants of this study with a more measurement oriented study supports this view. The intervention used in this study seems to appeal to customers with relatively low consumption.

---

6 The Finnish Electricity Market Authority regulates the content of the electricity bill in great detail. The industry is well aware that customers find the bill hard to understand, yet the discussions to change the regulation have not resulted in a positive outcome. Hourly metering will replace the estimates shown in the bill and thus reduce the information provided. This should make the bill easier to understand.

7 Large population standard deviation can be addressed with number of statistical techniques e.g. in sampling theory prior knowledge can be used to reduce the needed sample size for given accuracy. The analysis of table 3 also utilizes prior knowledge in standardizing the two data sets for comparison. Obviously the appropriate choice depends on the purpose of the study.

References

[1] European Union: DIRECTIVE 2006/32/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, Official Journal of the European Union 27.4.2006, Retrieved March 4, 2011 from the World Wide Web http://eur-lex.europa.eu/LexUriServ /LexUriServ.do?uri=OJ:L:2006:114:0064:0064:en:pdf

[2] Finlex: Hallituksen esitys Eduskunnalle laiksi energiamarkkinoilla toimivien yritysten energiatehokkuuspalveluista 26.6.2009, Retrieved March 4, 2011 from the World Wide Web http://www.finlex.fi/fi/esitykset/ he/ 2009 /20090111

[3] Motiva: National Energy Efficiency Agreements, Dec 13, 2010 , Retrieved March 18, 2011 from the World Wide Web http://www.energiatehokkuussopimukset.fi/en/about_the_agreements/

[4] Motiva: Energy efficiency agreements. Oct 11, 2010. Retrieved March 4, 2011 from the World Wide Web http://www.energiatehokkuussopimukset.fi/en/agreement_sectors /energy_sector/energy_ production/

[5] Motiva: Energy efficiency agreements. Oct 11, 2010. Retrieved March 4, 2011 from the World Wide Web http://www.energiatehokkuussopimukset.fi/en/agreement_ sectors/energy_sector/energy_services/

[6] Rouhiainen Virve: Sähkönmyyjän raportti asiakkaan energiankäytöstä, 9.6.2010. Can be downloaded at:http://www.energia.fi/content/root%20content/energiateollisuus/fi/ ymp%c3%a4rist%c3%b6%20ja%20energians%c3%a4%c3%a4st%c3%b6/energiatehokkuus/kirjasto/liitteet/s%c3%a4hk%c3%b6n%20k%c3%a4ytt%c3%b6raportti_loppuraportti_20100609.pdf?SectionUri=%2ffi%2fymparisto%2fenergiatehokkuus

[7] Motiva: Sähkölämmityksen tehostamisohjelma Elvari. Nov 24, 2010, Retrieved March 4, 2011 from the World Wide Web http://www.motiva.fi/koti_ja_asuminen/nain_saastat_energiaa/ sahko lammityksen tehostamis ohjelma elvari

[8] Motiva: Elvari-ohjelmassa julkaistut aineistot. April 2010. Asiakaskysely lukemalaskutukseen siirtymisestä, Retrieved March 4, 2011 from the World Wide Web http://www.motiva.fi/files/3959/Asiakaskysely_ Lukemalaskutukseen_siirtyminen_ja_ asiakas kyselyn_tulokset.pdf

[9] Kasanen Pirkko: Energianeuvonnan järjestäminen Suomessa. Sitran selvityksiä 7, 2009, ISBN 978-951-563-684-3 (URL:http://www.sitra.fi)

[10] Valonia: Valonia vuosiraportti 2008 (annual report 2008) Retrieved March 4, 2011 from the World Wide Web web document: http://www.valonia.fi/public/ download.aspx?ID=89887 &GUID={2CD99C0A-162D-4221-B8C8-7FDD5E9C4E59}

[11] Rouhiainen Virve: Decomposing Electricity Use of Finnish Households to Appliance Categories June 2009. 5th International Conference on energy efficiency in domestic appliance and Lighting, June 16-18, 2009, Berlin Germany.

[12] Statistics Finland, Data retrived from http://pxweb2.stat.fi/Database/StatFin/asu/asas/asas_fi.asp , on Feb 14, 2011

[13] Gölz Sebastian, Götz Konrad, Deffner Jutta: Smart Metering – a means to promote sustainable energy consumption? Socio-technical research and development on feedback systems, 5th International Conference on energy efficiency in domestic appliance and Lighting, June 16-18, 2009, Berlin Germany

[14] Anttonen: Changing Behaviour (2009). “Case Study 10. Energy Expert Programme.” Changing Behaviour. Retrieved March 4, 2011 from the World Wide Web: http://toolkit.energychange.info /case-studies/10

[15] Korsunova, Angelina: Encouraging energy conservation with 'no hard feelings': a two-part analysis of communication between energy companies and Finnish households. Jyväskylä: University of Jyväskylä, 2010, 213 p. ISSN 1457-1986; 95) ISBN 978-951-39-4080-5

[16] Nissinen Ari, Alku Panu, Heine Pirjo, Heiskanen Jan, Korhonen Marja-Riitta, Koski Pertti, Laitila Päivi, Lappi Risto, Laukkanen Pertti, Lehikoinen Sari, Lehtonen Matti ja Wings Sujit: Kotien reaaliaikainen sähkönkulutuksen mittaaminen ja havainnollistaminen- HEAT'07 projektin tulokset. Suomen ympäristökeskuksen raportteja 7, 2008 Helsinki. ISBN 978-952-11-3051-9

[17] Abrahamse W, Steg L, Vlek Ch, Rothengatter T: A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology 25: 273-291. 2005.

Sustainability – Measuring Environmental Impacts

Wayne Morris
Kevin Messner

Association of Home Appliance Manufacturers

Abstract

The term “Sustainability” is gaining much prominence lately with respect to judging the environmental impact of products. In the appliance industry, we measure the impact of many of the products by their energy efficiency or water efficiency. We also measure their safety, their performance, and their chemical composition. However, none of these measurements are linked outside of the manufacturing companies. But, we know that the environmental impacts of products are inextricably linked. We are beginning to see discussions about whether the continued reduction of energy usage or water usage of appliances will eventually lead to a reduction in the performance of the products. We know that increasing insulation in products to reduce energy demand can lead to greater materials with which to dispose at end of life. Truly, we can see that many factors in environmental impact of products are directly connected. How can we measure the overall environmental impact and reduce many of these elements within products through a holistic lens? To this end, the Association of Home Appliance Manufacturers (AHAM) has embarked on the first steps to try to develop a series of environmental product standards for sustainability. This effort was first begun in 2010 with significant studies of what literature and what environmental studies of appliances were available, and there are several. Next a series of discussions have taken place with not only the industry, but also with stakeholders from government, retail, academics, environmental advocacy groups, media, and others who are knowledgeable in the area of sustainability.

Introduction

The Association of Home Appliance Manufacturers (AHAM) is a trade association that represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM’s membership includes over 150 companies located throughout the world. In the U.S., AHAM members employ tens of thousands of people and produce more than 95% of the household appliances shipped for sale. The factory shipment value of these products is more than $30 billion annually. The home appliance industry, through its products and innovation, is essential to U.S. consumer lifestyle, health, safety and convenience. Through its technology, employees and productivity, the industry contributes significantly to U.S. jobs and economic security. Home appliances also are a success story in terms of energy efficiency and environmental protection. New appliances often represent the most effective choice a consumer can make to reduce home energy use and costs.

AHAM is also a standards development organization, accredited by the American National Standards Institute (ANSI). The Association authors numerous appliance performance testing standards used by manufacturers, consumer organizations and governmental bodies to rate and compare appliances. AHAM’s consumer safety education program has educated millions of consumers on ways to properly and safely use appliances such as portable heaters, clothes dryers, and cooking products.

What Do We Mean By “Sustainability?”

There are many definitions of Sustainability or Sustainable Development. The World Commission on Environment and Development was convened in 1983 by the United Nations. The commission was created to address growing concern "about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." In establishing the commission, the UN General Assembly recognized that environmental problems were global in nature and determined that it was in the common interest of all nations to establish policies for sustainable development.

The Commission (also known as the Brundtland Commission in tribute to its Chair, Gro Harlem Brundtland) in 1987 defined Sustainable Development as a way of development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." It contains within it two key concepts:

1. the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and

2. the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

The U.S. Environmental Protection Agency (EPA) has stated:

> "Over the past 30 years, the concept of sustainability has evolved to reflect perspectives of both the public and private sectors. A public policy perspective would define sustainability as the satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends. From a business perspective, the goal of sustainability is to increase long-term shareholder and social value, while decreasing industry's use of materials and reducing negative impacts on the environment.
>
> "Common to both the public policy and business perspectives is recognition of the need to support a growing economy while reducing the social and economic costs of economic growth. Sustainable development can be facilitated by policies that integrate environmental, economic, and social values in decision making. From a business perspective, sustainable development is accomplished by capturing system dynamics, building resilient and adaptive systems, anticipating and managing variability and risk, and earning a profit.
>
> "Sustainable development reflects not the trade-off between business and the environment but the synergy between them."

The appliance sector has been advancing with technology continuously since it first appeared in the early 20^{th} century. Today, technology advancements are occurring at an ever more rapid pace along with the size of many of the appliances. The main driver in the last 40 years has been to reduce the overall energy demands of the products and the achievements in this direction have been dramatic.

When the first life cycle analysis studies were performed on appliances in the latter 1990's, it clearly showed that energy during the use phase was the dominant driver on the environment. Today, while this is still a major contributor, it may not be the only major driver, and we need to be acutely aware of what those drivers may be. Through more advanced life cycle analysis approaches, we can better quantify the demands of these products on the environment.

Why Are We Measuring Sustainability?

Certainly we could be satisfied with just measuring the energy when the product is used, but as we continue to make improvements in this area, we need to be able to apply a life cycle study approach to the inter-relationship between energy and other environmental demand factors.

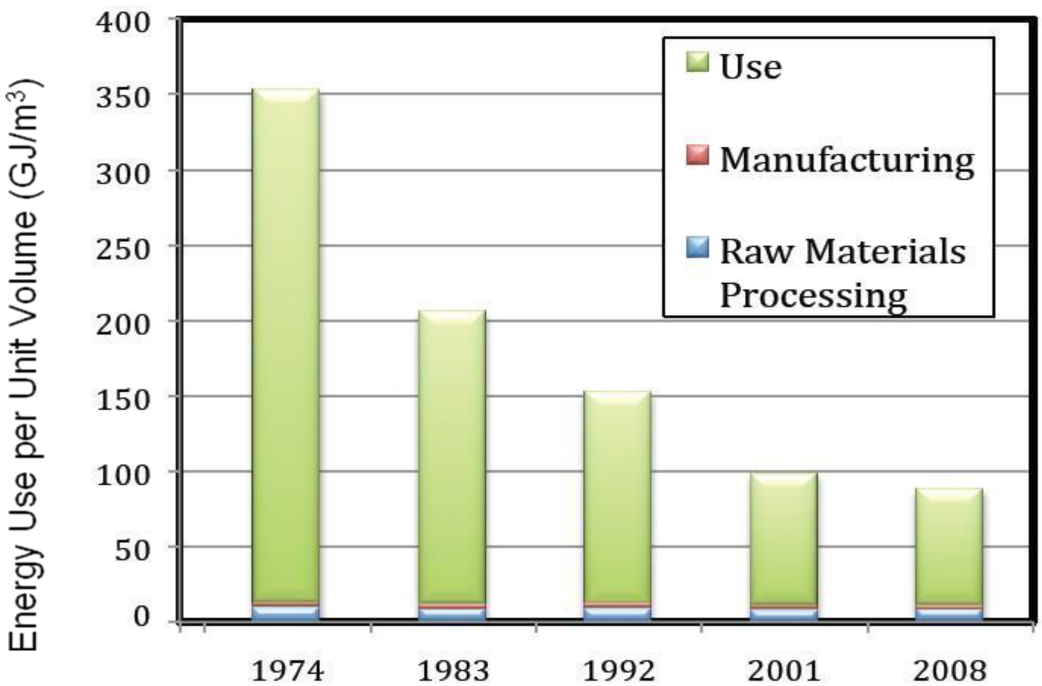


Figure 1: Appliance Remanufacturing and Energy Savings (Source: Boustani et al. (2010))

As home appliances become more energy efficient, relatively speaking, the proportion of energy impacts from other activities within the product life cycle are increasing (see Figure 1). While this shows energy, when we measure the full life cycle of the product, energy is one of several attributes we need to consider.

The key element will be the design of products for the future. An integrated way to quantify the environmental impact of products and to assess different product elements will assist design engineers with a methodology and tool with which to judge different designs and look for ways to reduce the overall demand on the environment.

Certainly today, many companies are already assessing the impact of their products on the environment. Many companies focus on this in their advertising and consumers are becoming more aware of the impact of their purchasing decisions on the environment. Increasingly, retailers are beginning to be aware that their purchasing decisions of what products they carry within their portfolio can have a definite impact on the overall environment. But, it is important that the tools we use have credibility, technical substantiation, and scientific principles of quantification at their core.

We currently see more than 350 marks, symbols or “ecologos” across a variety of product sectors (see Figure 2). Many of these represent certification programs. Some represent single-attribute programs and others look at more than one attribute. Certainly consumers could easily be confused with all these environmental marks if we are not careful with the creation of programs that are based on sound principles of science and which are organized under open and transparent standards programs with available programs for comparatively treating all companies in a business sector.

Figure 2: Ecologos (Source: CSA Standards)

Standards

AHAM believes that one of the best ways of assisting its member companies and others around the world is to develop open and transparent standards using the expertise of the industry and environmental standards experts, but also drawing on resources from outside the industry. To this end, we have employed a series of experts from several stakeholder communities, including The Sustainability Consortium, several individual retailers, U.S. Environmental Protection Agency, Environment Canada, Consumers Union, and several other groups. We are meeting regularly with these groups to discuss the process and the standards throughout their development. We believe a set of measurement standards will allow companies to judge their own products against those of other companies, and within their own product portfolio, in order to make decisions about future designs. Consensus standards development will allow all parties to present technical information and to participate among their peers.

Principles of Sustainability Standards Development

The AHAM standards development committee is committed to ensuring that the development of the standard follows the principles outlined in ISO 14020 on Environmental Labels and Declarations. These core principles, as applied to the sustainability standard for refrigeration appliances, are listed below:

1. The product sustainability standard shall be accurate, verifiable, relevant and not misleading.

2. Procedures and requirements for the product sustainability standard shall not create unnecessary obstacles to international trade.

3. The product sustainability standard shall be based on scientific methodology that is sufficiently thorough and comprehensive to support the claim and that produces results that are accurate and reproducible.

4. Information concerning the procedure, methodology, and any criteria used to support the product sustainability standard shall be available and provided upon request to all interested parties.

5. The development of the product sustainability standard shall take into consideration all relevant aspects of the life cycle of the product.

6. The product sustainability standard shall not inhibit innovation.

7. All organizations, regardless of size, should have equal opportunity to use the product sustainability standard.

8. The process of developing the product sustainability standard should include an open, participatory consultation with interested parties.

9. Information on the environmental aspects of products and services relevant to the product sustainability standard shall be available to purchasers and potential purchasers.

10. The focus of the product sustainability standard shall be on improving the sustainability performance of products designed today and in the future, rather than those designed in the past. We support the environmentally responsible disposal and recycling of appliances currently at end-of-life through existing initiatives such as the Appliance Recycling Information Center (ARIC) and North American Appliance Resource Management Alliance (NAARMA).

11. The product sustainability standard should lead to the differentiation of environmentally preferable products.

12. The requirements for the product sustainability standard should evolve with changes in the marketplace.

13. The requirements for the product sustainability standard should not set pricing or other commercial terms.

Tools

As mentioned earlier, we are fortunate to have available a number of excellent research studies that have been conducted within this arena. A number of life cycle analysis studies have been conducted on a few of the products within the scope of AHAM. However, many of these studies have been conducted on products distinctly different from those produced today, or in North America. Also, we believe some of these studies, based on their intended purposes, did not cover many of the important attributes. Therefore, in our standards development process, AHAM, CSA Standards Group, and UL Environment (ULE) partnered to produce more comprehensive life cycle analysis and “hot spot” analysis of many of these products for today’s product designs. These life cycle analyses and hot-spot analysis will guide the development of the selection of the major attributes and help us derive the relative weighting of these attributes. Figure 3 is an example of the life cycle screening.

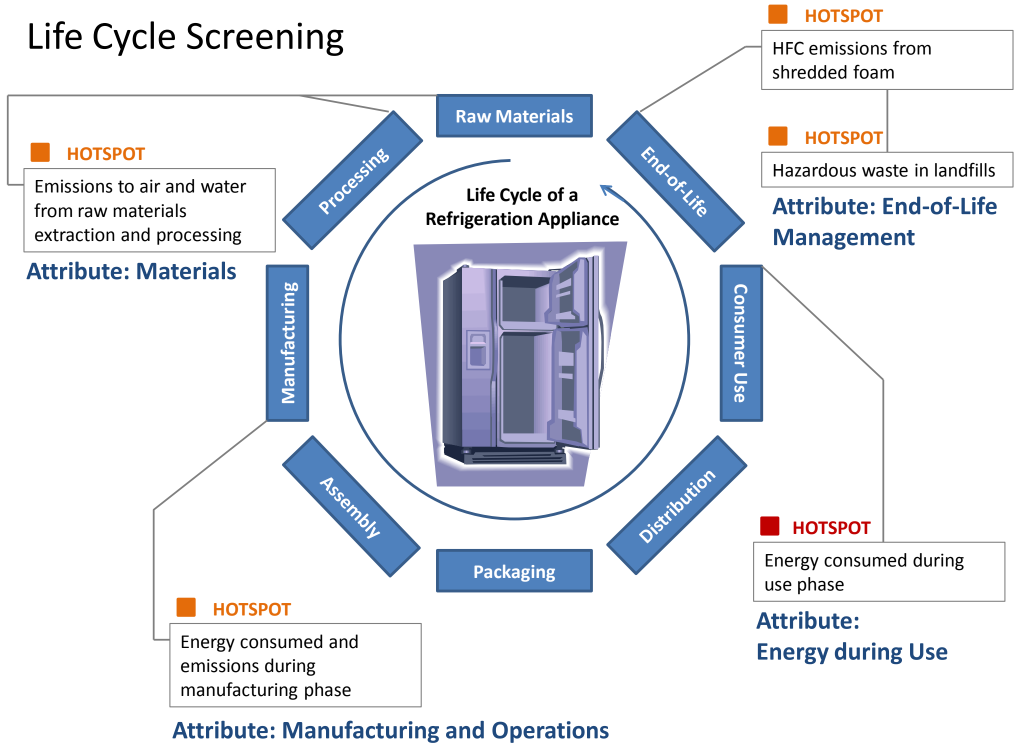


Figure 3: Life Cycle Screening

While we are early in the process of appliance sustainability standards development, we have identified several key attributes with impact on the overall environmental position of these appliances. These may include:

- Materials
- Energy During Use
- Manufacturing and Operations
- Performance
- End-of-Life Management
- Innovation

Nomenclature

We plan to utilize the nomenclature of environmental effects as found in the ISO 14000 series of standards as in Figure 4.

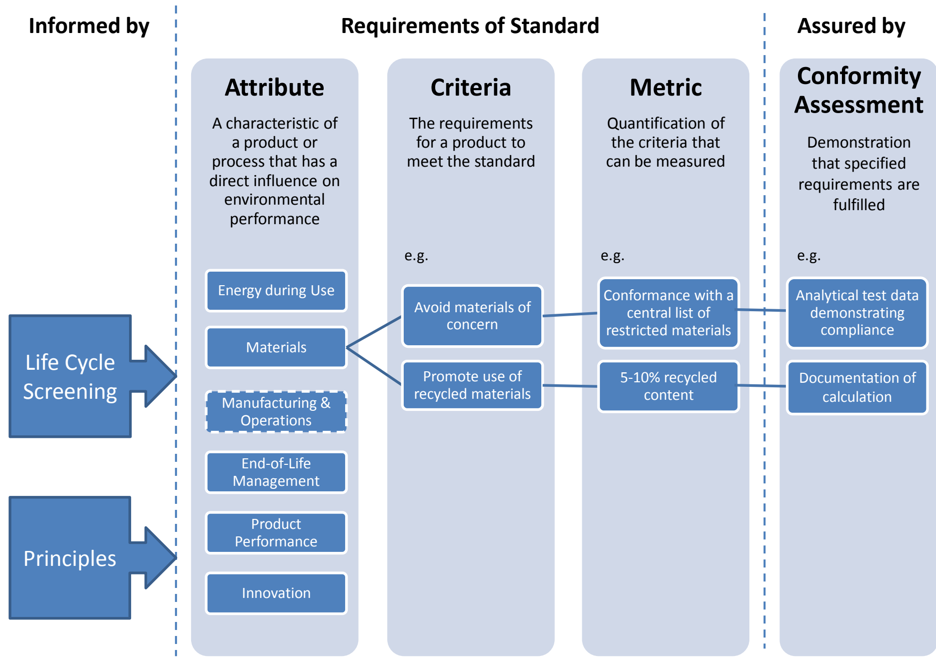


Figure 4: Standards Requirements

Development

Our goal is to develop consensus standards within the framework first of the American National Standards Institute (ANSI) and Standards Council of Canada (SCC) framework for North American standards. Following this, we will discuss the opportunities for a new work document under ISO or IEC environmental standards. Our intention is to have some of these standards available for “testing” the standard by the end of 2011. We will begin with refrigeration products to be followed by other major appliance standards. In addition, we are also developing standards that apply to the portable and floor care types of appliances.

AHAM has joined together with three organizations to assist with these standards developments: CSA Standards, ULE, and Five Winds International.

CSA Standards is a leading standards-based solutions organization serving industry, government, consumers and other interested parties in North America and the global marketplace. Focusing on standards and codes development, application products, training, advisory and personnel certification services, the organization aims to enhance public safety, improve quality of life, preserve the environment and facilitate trade. For more information, visit www.csa.ca.

UL Environment (ULE) supports the growth and development of sustainable products and services in the global marketplace through standards development and independent third-party assessment and certification. ULE is a wholly owned subsidiary of Underwriters Laboratories, a global leader in conformity assessment that has been testing products and writing standards for more than a century. ULE currently offers Environmental Claims Validation (ECV), a service testing and verifying manufacturers’ self-declared environmental claims, Sustainable Products Certification (SPC), a service testing and certifying products to accepted industry standards for environmental sustainability and Energy Efficiency Certification (EEC), a service testing and verifying product compliance with mandatory and voluntary energy efficiency regulations and programs. ULE is developing additional environmental standards, as well as training and advisory services to support organizations in the sustainable products and services industry. For more information, visit www.ulenvironment.com.

Five Winds International, an internationally recognized sustainability consulting firm, has been selected as a project manager for the AHAM project. Five Winds brings twelve years experience in improving the sustainability of companies and has been instrumental in helping to write international environmental standards.

Conclusion

Through the combined efforts of our industry and other stakeholders, we believe that the AHAM-CSA-ULE sustainability standards will offer the appliance industry and others in this industry segment a set of valid and objective standards for measuring product sustainability for future designs and for improvements to the environment. The appliance industry is pleased to continue our leadership in the area of environmental responsibility and we look forward to the technical expertise within many stakeholders to produce strong, technical product sustainability standards that can help in the design of the next generation of appliances.

An Overview of U.S. Residential Consumer Electronics Programs

Marti Frank and Jane Peters

Research Into Action, Inc.

Gregg Hardy

Ecos Consulting

Abstract

Consumer electronics are driving a significant increase in energy consumption in the U.S. residential market. In the typical U.S. home up to one-third of all electricity is devoted to electronics like televisions, computers and game consoles.

Since 2008, several energy efficiency programs have been initiated to address consumer electronics. Implementers face several confounding market forces, among them the volume of products (the number of installed products is in the billions, with millions of new devices purchased annually), the variety of devices, the near continuous rollout of new products, the rapid evolution of new technologies, the often small electricity consumption of individual devices, and consumers' lack of awareness of energy efficiency as a product feature.

This paper reports on current U.S. efforts to increase penetration of energy efficient consumer electronics by implementing voluntary incentive programs (typically funded by utilities or public benefit corporations). First, it provides an overview of the consumer electronics market in the U.S., including a review of the barriers facing energy efficiency programs. Second, it summarizes current U.S. approaches and describes the theoretical and logistical aspects of the various programs now underway. Third, it assesses the strengths and weaknesses of these approaches based on the most recent research on this market. Finally, the paper suggests policy and programmatic implications and recommends elements of international programs that might beneficially be employed in the U.S.

The Gadget Problem

The U.S. has a gadget problem. Consumer electronics, like TVs, computers and game consoles, are driving a significant increase in energy consumption. Together with other plug load products they consume more electricity in U.S. buildings than any other single electric end use.[1] Some studies indicate consumer electronics alone may account for 10% of total U.S. electric consumption. In the typical U.S. home the figure is more striking: up to one-third of all electricity is devoted to electronics [1, 2].

Several factors distinguish the electronics market from other markets and complicate efforts to address it. The volume of products is tremendous - the number of installed units is in the billions, with millions of new devices purchased annually. The variety of devices exceeds any other market with which efficiency programs have experience – there are at least 100 types of plug load products, from the ubiquitous television or toaster to the less common pool pump or waterbed heater. New product models are released continuously and new technologies debut annually. In the majority of products, energy efficiency is not a key product design feature.

Even if the efficiency community's standard-setting efforts could keep up with the rapid rollout of new product models and technologies, there would be another more daunting hurdle. The annual energy consumption of any one device may be small absolutely, with correspondingly small potential savings, or small relative to the product's price. As a result, approaching this market with the typical appliance program design model, in which consumer receive a cash incentive for buying a qualified product,

---

[1] "Plug load" is the energy consumed by devices that plug into a wall outlet and obtain power from the building's electrical system. In the U.S. there has been some inconsistency in the products that make up the plug load. Certain devices are always included – TVs and PCs for example. Portable lighting may or may not be included. White goods like refrigerators, clothes washers and dishwashers are typically excluded, but not always.

may be rendered practically worthless. Several program managers commented that any cost-effective incentive will be too small to alter the customer's buying decision. So by what other means can we target these products?

A blanket of state-level performance standards or a federal standard for the highest energy-consuming products may be an effective tool when used to stem the energy consumption of electronics products. However, currently the U.S. does not have mandatory minimum energy performance standards (MEPS) for any consumer electronics products. California, in 2010, was the first and, thus far, the only state to establish a mandatory energy efficiency standard for televisions. Legislation that would apply a “California-style” television MEPS is pending in Oregon and Washington.

Future action at the federal level is uncertain. Policy experts note that some policy makers appointed by President Obama have a strong desire to increase the breadth of efficiency standards to include more plug load products. However, the same experts also caution that consumer electronics manufacturers have successfully lobbied against regulation in the past and continue to do so.

Voluntary Consumer Electronics Efficiency Programs

Despite, or perhaps as a result of, the lack of regulatory action, interest in the efficiency of consumer electronics has grown quickly in the U.S. over the last five years. Efficiency experts recognized that electronics, a group of products that had been all but written off as “miscellaneous” or “other” in the majority of studies, were starting to account for a significant portion of total electric load. Researchers, program administrators and implementers began thinking about how to apply the voluntary programmatic structures they had been using for the past twenty years (and more) to this new group of products.

At the end of 2010 there were 22 consumer electronics programs in 14 states with a total investment above $70 million. Another 18+ organizations in 14+ states were investigating opportunities. [3]. Televisions were the most commonly targeted device type, followed closely by computers and monitors. “Smart” power strips (power strips with power management features like timers, master/subordinate outlets or occupancy sensors) and other power management strategies made up the next most popular product category. Set-top boxes and imaging equipment (copiers and multi-function devices) are included in a few programs and under consideration by a handful of others for future inclusion.

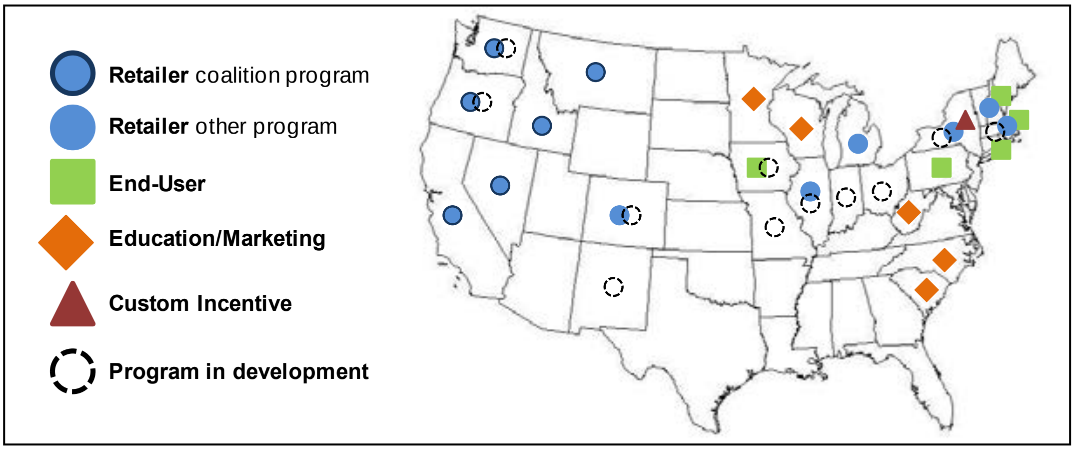
The Geography of Electronics Programs

Figure 1 shows the location and type of the 31 consumer electronics programs in the field or in development. The first and largest electronics programs are in the Western U.S., in California, Oregon, Washington, Montana, Idaho and Nevada. This is perhaps not surprising because California and the Pacific Northwest (PNW) spend more than $1 billion on efficiency annually, more than any other region in the country. These states were some of the first to run efficiency programs and are now home to an abundance of experienced efficiency program managers (at utilities and non-profit program administrators) as well as consultants (implementers and researchers). Program administrators in much of the West are working collaboratively to align their programs, with a majority of the programs sharing an implementation contractor and all of them sharing a data processing consultant and evaluation methodology. All of the programs also follow a similar mid and upstream implementation model, in which incentives are paid to retailers and manufacturers for sales of qualifying products.

Several smaller electronics programs can be found in the East coast states of Connecticut, Pennsylvania, Massachusetts, New Hampshire, New York and Vermont, another region with a strong history of efficiency programs. However, these programs differ from those in the Western part of the country in a few marked ways: the majority are pilots, typical program funding is about one-tenth that of the coalition programs and each is operating independently of the others. Their implementation models differ from one another and from the West coast programs too. Three of the six employ a downstream implementation model (in which incentives are paid to the end-user) and one program takes an approach unique in the U.S. by focusing exclusively on power management rather than aiming to increase the penetration of efficient products. Two programs, one of which launched in early 2011, follow the retailer model and are similar to the West coast programs.

The lack of incentive programs in the Midwest region, particularly in states where other energy efficiency activities are taking place, is worthy of note. Two programs provide financial incentives, both of which are small, one of which is a pilot. The other programs are solely focused on education. Although Midwest utilities are familiar with the coalition program model being implemented in California and the PNW, and discussions about participation took place over the past two years, no utility has yet signed on. An energy efficiency expert in the region suggests that the reasons are similar to the barriers faced by all energy efficiency program designers in the consumer electronics space: small per-unit energy savings and extensive and expensive data tracking requirements for mid and upstream programs. In addition, Midwest utilities may also believe they still have "low hanging" energy savings to capture through more cost-effective programs targeting compact fluorescent (CFL) light bulbs and weatherization, measures with established program design models and firm savings estimates.

Figure 1: Map of U.S. Consumer Electronics Initiatives by Model, 2010



Four Electronics Program Models

There are four program models currently in the field, three of which have incentives at their core (Table 1 and Figure 1):

- **Retailer Model.** The most common program implementation model involves paying per-unit incentives to retailers (and occasionally to manufacturers) for sales of qualifying products. The model was first applied to consumer electronics by Pacific Gas & Electric, a California utility, in 2008-2009. Programs implementing this framework and sharing an implementation contractor are currently operating throughout California, the Pacific Northwest states of Oregon, Washington, Idaho and Montana, and Nevada (referred to here as "coalition" programs). Six other programs are employing a similar retailer incentive approach, half of which are pilots.
- **End-User Model.** In this approach incentives are paid directly to the customers for each purchase of a qualified product. This strategy is less common than the retailer incentive model. It is used by pilot programs and programs with smaller budgets.
- **Custom Incentive Model.** In this program approach, used only in New York to-date, manufacturers of "smart" power strips work directly with the funder to negotiate an incentive payment structure.
- **Education/Marketing Model**. Programs that employ only education and marketing to end-users to encourage purchase of efficient electronics. Materials and information were provided during home energy audits, online, public presentations, bill stuffers, print ads and newsletters.

Table 1: U.S. Consumer Electronics Program Models, 2009-2010

Program Model	Targeted Population	Products	Location
Retailer	Retailers and manufacturers	TVs, PCs, monitors, printers/multi-function devices (MFDs)	Coalition Programs California Idaho Montana Nevada (starting 2011) Oregon Washington Others Colorado (pilot) Illinois (pilot - discontinued) Massachusetts Michigan (pilot) Pennsylvania Vermont
End-User	End users	TVs, PCs, monitors, imaging equipment, “smart” power strips	Connecticut (pilot) Iowa Massachusetts New Hampshire Pennsylvania
Custom Incentive	Manufacturers	“Smart” power strips, set-top boxes	New Jersey New York
Education/Marketing	End users	TVs, PCs, monitors	Minnesota North Carolina South Carolina West Virginia Wisconsin

The Retailer Model: Biggest Programs, Broadest Reach, Early Success

The retailer model is the program approach taken not only by the greatest number of programs, but also by the biggest and most fully developed programs. There are a few likely reasons for the model's predominance. Proven success is not one of them, as program results are only starting to trickle in as of early 2011, and the program was widely adopted *before* its success was demonstrated. What seems more likely is that the retailer model has prevailed because it was developed by a large, well-funded and well-organized utility that was first-to-market in the consumer electronics arena, its program theory is sophisticated and appealing, and the utility that developed it, along with the implementation contractor, actively sought participation from other program administrators in a “coalition” effort.

The “Coalition” Programs: California, the Pacific Northwest and Nevada

The largest consumer electronics effort in operation today is a cooperative initiative among four California utilities, a Nevada utility and the Northwest Energy Efficiency Alliance (NEEA), a public non-profit corporation that supports efficiency in Oregon, Washington, Idaho and Montana. Although the initiative is funded and branded separately in each geographic area, most programs employ the same implementation contractor and all have adopted a similar program framework. The California utilities began implementing the program in 2009. The NEEA program was piloted in late 2009 and entered full program status in 2010. Nevada piloted the program in 2010 and will implement it throughout the state in 2011.

The coalition programs are the most significant and far reaching of the voluntary programs in the U.S. to date – both in terms of dollars spent and geographic reach. Together, the total program budgets are estimated at $15 million to $20 million. The programs cover much of six states, which together account for approximately 16% of the U.S. population.

Other programs are employing the retailer model and in most cases they are aware of and making an effort to align their qualified products with the coalition programs. They include programs in Massachusetts, Pennsylvania and Vermont and pilots in Colorado and Michigan. However, these programs operate independently of one another and are implemented by different contractors than the coalition programs.

The Details

Retailer model programs currently focus on one, some or all of four product types: televisions (TVs), desktop computers (PCs), monitors and printers/multi-function devices (MFDs). Key program activities are the payment of incentives (between $5 and $25 per unit) to retailers for each qualifying product sold, and education and marketing to retailers and end-users. The programs' objectives are to increase the market share of qualified products and to affect retailer stocking practices to make more qualified products available to end-users.

The programs support retailers with point-of-sale materials and end-user talking points as well as offering opportunities for collaboration on other initiatives. Outreach efforts to end-users include point-of-sale materials and websites that educate end-users about the benefits of efficient electronics and help them find qualified products and local retailers. Figure 2 shows a screenshot of the program website in NEEA territory (PNW). Figure 3 shows samples of a point-of-sale product labels from the PG&E (California) program.

Figure 2: Screenshot of NEEA program website homepage [7]

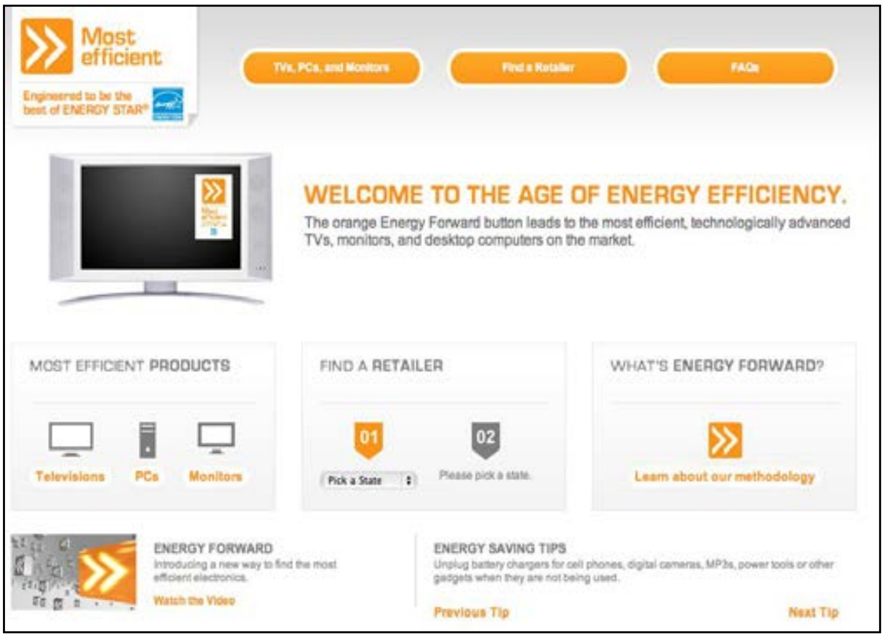


Figure 3: PG&E (California) Point-of-Sale Materials [10]

Program Theory: Retailer as Gatekeeper

The coalition programs, as well as the programs in other areas, employ a mid and upstream implementation model premised on a theory about how the consumer electronics market works that places retailers in a key position of power. “Retailers play the strongest role in the [business-to-consumer] market since the vast majority of consumer electronics sales occur through this channel,” according to a description of the California programs [8]. The distribution pyramid narrows to a single point, with a small number of big box retailers dominating sales and with product selection within each retailer organization controlled by “category buyers,” who determine which products appear on their shelves.

According to the program theory, it is the retail category buyers, not customers, who hold the key to improving energy efficiency. They are the “gatekeepers” who “greatly influence” the products available to U.S. consumers. The incentive payments, though nominal, are expected to entice buyers to shift their product mix in order to fatten what are, by all accounts, the incredibly slim margins in electronics retailing [14].[2] The program can thus “leverage the market at the fulcrum of decision-making . . . [generating] the greatest effects at the lowest cost” [8]. Increased stocking of qualified products, together with education for salespeople and consumers, is theorized increase the sales of those products and ultimately transform the market, as manufacturers respond to increased demand for qualified products by designing efficiency into more of their products.

Early Success in the TV Market – and its Consequences

The coalition programs were among the first forays into consumer electronics in the U.S. Estimates of their market impact will be viewed with much interest by other regional efficiency administrators and third-party implementation firms, all of whom are curious to see to what extent their program theory proves accurate and their implementation approach succeeds.

Early evaluation studies and anecdotal findings suggest the coalition programs have significantly affected the TV market. The coalition programs report they’ve seen average TV efficiency increase by 40-60% over the course of the programs, are working with retail partners that make up 70% of the market, and have incented about 850,000 units [6]. NEEA reports that, in the Pacific Northwest, demand for qualified TVs “surged” by 15% with resulting savings estimated at 3.6 aMW in 2009, three times the program’s initial goal [7]. Other retailer model programs have also provided anecdotal reports of success in the TV market, noting increases in retailer stocking and sales of qualified products.

The transformation of the TV market has not been limited to the Western regions of the U.S. where large programs are active. Because these programs are working with national retail chains, changes in buying and stocking practices in one region are affecting the sales baseline across the country. A pilot program manager remarked, “There is spillover,” and theorized that the success of the coalition programs will require others to select qualified measures carefully to stay ahead of the market and avoid free-ridership. The fast-paced TV market has already contributed to the end of one pilot program and it continues to frustrate program managers who, despite seeing rising penetration numbers and knowing product requirements need to be tightened, feel helpless to participate because their funding utilities are bound by the slow moving regulatory process. An efficiency expert theorized that spillover may be one reason for the lack of programs in some regions of the U.S., because it

[2] For example, Best Buy, one of the top three electronics retailers in the U.S., has come under scrutiny among analysts for its low margins, a fact that has hurt its share price in the past.

makes it difficult for evaluators to attribute impacts to local programmatic efforts and thus the programs are perceived by program managers as a risky investment for program managers, who may not be able to claim credit for their work.

Evaluation Challenges

In fact, adaptation and attribution may prove to be two of the biggest challenges for consumer electronics programs. All programs, no matter the model, need to document their impact on the market in order to establish their relevance and estimate resulting energy savings. But it is difficult for mid and upstream programs to do so because they do not collect their own unit sales data, have no way to confirm the eligibility of measure recipients and are just one of the forces behind the desired outcome.

The coalition programs addressed these problems by developing an innovative (and expensive) evaluation approach that includes baseline studies conducted prior to program launch and periodically throughout the program, careful activity tracking by program managers during program implementation and extensive data analysis by a third-party contractor.

The evaluation requirements of the retailer model provide yet another explanation for the absence of midstream programs in many parts of the U.S. The cost and challenges associated with midstream program evaluation played a role in the termination of one pilot program and motivated a major modification to another pilot, when it was expanded into a full program. This pilot program paid incentives to retailers based on "lift," as the coalition programs do. When the full program was rolled out the implementers switched to a traditional midstream rebate model, in which the retailer receives an incentive payment for every unit sold. According to the program manager, the data required to calculate "lift" was too onerous for retailers and too expensive and time-consuming for the implementers. The manager acknowledged that using a traditional midstream rebate may increase costs but it enabled the program to engage with more retailers and dramatically increase participation and energy savings.

Strengths of the Retailer Model: We Know How to Do This!

For program administrators and implementers, a retailer program approach has some distinct advantages. Chief among them is its familiarity. U.S. energy efficiency programs have a long history working successfully with product retailers to increase sales of energy efficient white goods and light bulbs. The "SPIFF," circuit riders, merchandising displays and POS materials are all familiar territory for program managers, administrators, evaluators and implementers.

In addition U.S. West coast utilities, Pacific Gas & Electric in particular, have extensive experience running mid and upstream incentive programs to influence light bulb stocking practices. Several utilities ran large scale incentive programs for compact fluorescent lights (CFLs) starting in 2001, many of which involved close working relationships with retailers and manufacturers. Evaluations showed these programs to be cost-effective and successful at transforming the market for CFLs. In fact today, standard CFLs are being phased out of efficiency program portfolios in the Western region because the market is considered to have been transformed and no further program interventions are required.

The possibility of affecting widespread change by targeting a small number of retail buyers is extremely attractive for its potential cost effectiveness. In fact, this is one of the key reasons program managers say they implemented the retail model, particularly in regions where utility programs must pass stringent cost-effectiveness tests. In addition, retail buyers are an easy target population to identify (the position title and role is the same at nearly every retail organization), an important but often neglected element in program design.

A Few Cracks in the Program Theory

Success in the TV component of the retailer model programs would appear to confirm the program theory that retail buyers are the market's gatekeepers. However, it is unclear whether the payment of incentives is actually responsible for the changes in the market, and some evaluators have expressed doubt on this point.

Other efficiency experts question the continuation of payments, arguing that incentives motivated buyers' initial shift to stocking more efficient products, but that these products' positive reception by customers ensures the stocking practices will continue, regardless of incentives. The question thus arises as to whether continued incentive payments are resulting in efficiency gains that would not have occurred otherwise ("additionality"), or whether retail buyers continue to accept incentive payments for actions they would have taken even without them ("freeriders").

In addition, many retailer model programs experienced far less success in affecting the PC market, and NEEA dropped PCs and monitors from their program in 2011. There are several possible reasons for the programs' lesser affect on stimulating sales of efficient PCs:

- Fewer PCs are sold in retail stores, where the programs' efforts were based.

- PCs are highly customized by end-users and it is unclear whether customers ordering PCs online were presented with information about the efficiency of their selection or alternate options to increase efficiency.

- An evaluator well versed in the market theorizes another barrier may be the polarity of the desktop PC market. The majority of sales occur at either the top or the bottom of the market. At the high end (in both price and computing power), product features are seemingly inseparable from energy consumption - PCs purchased for gaming or graphics production require components that result in energy consumption that exceeds efficiency standards. At the low end, buyers who put cost ahead of all other characteristics select the least expensive model, regardless of its efficiency.

- A desktop PC manufacturer suggested that incenting retailers will not affect PC product design because efficiency levels are determined overseas by original design manufacturers (ODMs), who design and manufacture PCs for U.S. brands. Because energy efficiency is typically low on a brand's desired list of features, it is often dropped from the final product specifications in order to meet a low price point.

Finally, interviews with market actors draw the market transformation potential of retailer incentives into question. The coalition program theory posits that retailers' stocking practices directly influence on a manufacturers' product design decisions. However, the precise weighting of various influences on the selection of product features is hardly systematic and even manufacturers are hard-pressed to explain how they balance customer demand, internal market research and retailer requests. Yet none of the TV manufacturers, or any of the more than 40 manufacturers interviewed over the last two years for two market characterization studies, gave particular weight to the demands of retailers over other sources, except in the case of private label products (when a retailer commissions the manufacture of a product for sale under its own brand) [11]. In fact one manufacturer, when asked to comment on the program's market transformation theory, replied that it was like tossing a stone into a pond. The effects of the program would certainly ripple outward but the program's impact on manufacturers would be delayed in time and decreased in effectiveness, when compared to an alternative – working directly with manufacturers to alter product designs.

End-User Model

In 2010, the few programs utilizing end user incentives were primarily pilots and programs with budgets in the hundreds of thousands of dollars, small relative to the coalition programs' budgets in the tens of millions. These programs were often focused on TVs, with rebates of $25 to $50, and PCs and monitors, with rebates of $3 to $10. Only one program offered rebates on imaging equipment (copiers and MFDs) of up to $45.

The extensive evaluation requirements faced by U.S. programs make a customer rebate preferable to a mid or upstream program for administrators seeking a program model in which the implementation and evaluation approaches are familiar and relatively simple. At least two programs selected the end user model specifically for this reason. Program managers noted that paying incentives to end users is "an established method," the savings can be firmly linked to the funder's service territory and the approach does not require extensive data collection and market analysis.

Some programs found an additional benefit to the end user incentive: it can be implemented with a mail-in rebate (rather than an in-store markdown). This was attractive to programs that operate in rural areas with few retail stores. Program managers commented that a mail-in rebate is more equitable because customers can claim an incentive for any qualified purchase, regardless of its source and utilities without many (or even any) retailers in their service territory can still offer the program to their customers.

Proponents of the retailer model often argue that cost effective per-unit incentive levels are too small to influence a customer's purchase decision. For example, it seems unlikely that a $20 rebate will influence the purchase of a $500 product. The findings from the end-user programs will hopefully shed light on this hypothesis.

Custom Incentive Model: New York's Experimental Design Approach to Power Management

The New York State Energy Research and Development Authority (NYSERDA) is a public benefit corporation that helps New York State meet its energy goals by reducing consumption and promoting the use of renewable sources. NYSERDA's approach to consumer electronics is unlike any other in the U.S. The program differs markedly from the predominant retailer and end-user models in both the products it targets and the approach to setting incentive amounts.

NYSERDA made a conscious decision *not* to target TVs and PCs because it classified them as "luxury" products, a decision that was not without some contention. Instead, the organization chose to address standby load, a market it felt was going unanswered. Their program focuses on power management technologies: smart power strips, timers and thermostats, energy monitors and management systems, and whole-house switches.

NYSERDA is not the only funder to address power management (it is also covered by seven other programs that incent the purchase of smart power strips) but it is the only program to use a custom, rather than prescriptive approach to setting an incentive structure.

NYSERDA's smart power strip program takes an experimental design approach. The organization negotiates the incentive amount and agreement structure with each manufacturer individually. In 2010 it ran 14 different promotions with seven manufacturers, and found varying levels of success with each. One of the more successful promotions was a manufacturer's "buy 6 get 6 free" offer to retailers. Retailers found it to be a low-risk way to introduce smart strips in their stores. Based on its success, NYSERDA is advising other manufacturers to adopt the model in 2011.

Conclusions and Recommendations

Several activities and strategies, some modeled on work conducted outside the U.S., may help meet the challenges of the electronics market.

Conduct Regular Monitoring and Saturation Studies

Regular monitoring and saturation studies need to be undertaken every two years at a minimum in order to provide up-to-date market data for the fast-changing electronics market. With one exception, the most recent U.S. monitoring studies were conducted in 2006 and are already out-of-date. For example, in one study only one of the 10 cable set-top boxes metered included digital video recording capability; Currently 30% of all boxes ship with this feature [12, 13].

The problems that result from a lack of current data can be seen across the energy efficiency spectrum and in unexpected places. A recent pilot study of deep energy residential retrofits, for example, the authors relied on one of the out of date 2006 studies to make projections about plug load energy consumption. Not surprisingly, they found actual consumption in the retrofitted homes to be 150% of estimates [5].

Australia provides a useful model for the U.S. The country's Bureau of Statistics conducts appliance saturation studies every three years and in-home monitoring studies (specifically aimed at measuring standby power) every five years. Regular saturation and energy use data, collected at the federal level would be useful to program managers and evaluators, reduce individual program costs, and likely reduce the barriers to the retailer model for smaller, risk-averse programs.

Set High Energy Efficiency Targets in a Roadmap Format

The fast paced nature of the consumer electronics market is one of the most challenging issues for program designers and implementers due in part to the often slow moving nature of the program funding and approval process. A model for an approach to meeting this challenge can be found in Japan's Top Runner program, in which today's "reach" efficiency levels become tomorrow's minimum energy performance standards.

One way to implement this in U.S. programs (where the farthest outlook out may be as little as one to three years) is with a "roadmap" format. Interestingly, this is a strategy the electronics industry commonly uses in setting its own standards. For program designers, a roadmap means a plan for product qualification levels that:

- Reaches to the end of the projected program timeline, and even beyond
- Gets reviewed and updated on a regular basis throughout the program
- Lists specific milestones to be met, with targets attached to each that increase in stringency at regular intervals

Consider Targeting Manufacturers as Program Partners

None of the current electronics programs have focused significant effort on engaging manufacturers and targeting them directly to influence more energy efficient product designs. This strategy may yield benefits for several reasons. Efficiency programs typically seek out leverage points – where a small effort can yield big changes. While retail buyers are certainly such leverage point, manufacturers' product design teams are another and, like retailing, manufacturing is a consolidated market. In most products a small number of manufacturers account for 80-100% of total sales. In addition, the competitive nature of the sector means the participation of even a single manufacturer may lead others to join. Manufacturers also make several product types, so a successful engagement may allow a program to target multiple product types. However, an upstream program strategy that targets manufacturers will face the same attribution and evaluation challenges of the midstream retailer model.

Consumer Electronics Programs 2011: State-of-the-Art? Not Yet

The programs on the ground in 2011 can all be considered first generation efforts. They are the first attempts to target a limited set of specific products. Many programs have modified their approaches based on preliminary findings. A few pilot programs were discontinued, others continue to modify their approach. Even the coalition programs are beginning to diverge, especially in measure selection.

The retailer model coalition programs have developed the most sophisticated program theory and evaluation approach and believe they have achieved marked success in the TV market. The alignment of multiple programs across a large geographic area addresses one of the most pressing barriers to success in the consumer electronics market: Product manufacturers are international but efficiency funding is local. But even this effort struggles to navigate the complex relationships between market actors, rapid change in technologies, continuous improvement in device energy efficiency and the diversity in product distribution channels. And, currently, the retailer model appears inaccessible to programs without the budget or staff to undertake the required data collection and evaluation activities. Future evaluation will hopefully shed light on how the results of the various program models compare.

Despite the significant accomplishments of the many programs in the field today, energy efficiency program administrators face the fundamental challenge of designing programs that address the realities of the electronics market while working within the constraints imposed by U.S. energy efficiency funding and evaluation requirements. What does seem certain is that next-generation programs will build on today's lessons learned and develop creative solutions to market barriers.

References

[1] Chase A., Ramos R., and Pope T. *Consumer Electronics: Market Trends, Energy Consumption and Program Recommendations, 2005-2010*. Prepared for PG&E by Energy Solutions. 2006.

[2] Consortium for Energy Efficiency. *Consumer Electronics Efficiency Program Summary. Updated December 30, 2010*. Available at http://www.cee1.org/resid/rs-ce/consumer_electronics_prog_sum.php3

[3] Energy Information Administration. *Annual Energy Outlook 2009: With Projections to 2030*. Report # DOE/EIA-0383(2009). Energy Information Administration: Washington, D.C. 2009. Available at http://www.eia.doe.gov/oiaf/archive/aeo09/pdf/0383(2009).pdf.

[4] Energy Information Administration. *Annual Energy Outlook 2007: With Projections to 2030.* Report # DOE/EIA-0383(2007). Energy Information Administration: Washington, D.C. 2007. Available at http://www.eia.doe.gov/oiaf/archive/aeo07/pdf/0383(2007).pdf.

[5] Keesee M. Deep *Energy Retrofits: Four Real World Examples and Lessons Learned*. AESP 21st National Conference & Expo. Orlando, Fl.: 2011.

[6] Northwest Energy Efficiency Alliance and Pacific Gas & Electric. "Business and Consumer Electronics: From Inspiration to Implementation." ENERGY STAR Partners Meeting, Denver, Colo.: October 2010. Available online at: http://www.energystar.gov/ia/partners/downloads/meetings/2010/Panel%202_Bresko_Cino.pdf

[7] Northwest Energy Efficiency Alliance. Energy Efficient Electronics website. Accessed January 24 and April 24, 2010. http://energyefficientelectronics.org.

[8] Opinion Dynamics Corporation. *Statewide Business And Consumer Electronics Baseline Study: Final Report.* Study ID# PGE0283.01. Prepared for Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric. Oakland, Calif.: 2009. Available online at: http://www.calmac.org

[9] Opinion Dynamics Corporation. *The Market for Energy Efficient Electronics: Pre-Program findings on consumer perceptions and retail shelf stocking practices*. Report #10-219. Prepared for Northwest Energy Efficiency Alliance. Portland, Ore.: 2010. Available online at http://neea.org/research/reports/10-219_Combined.pdf

[10] Pacific Gas & Electric. Save Money Save Energy website. Accessed January 24, 2010. http://www.pge.com/mybusiness/energysavingsrebates/buyersguide/bce/.

[11] Peters J., Frank M., Van Clock J. and Armstrong A. *Electronics and Energy Efficiency: A Plug Load Characterization Study*. Study ID# SCE0284. Prepared for Southern California Edison. Rosemead, Calif.: 2010. Available online at http://www.calmac.org/publications/BCE_FINAL.pdf

[12] Porter S., Moorefield L. and May-Ostendorp P. *Final Field Research Report*. Study ID# CEC-500-2004-030. Prepared for the California Energy Commission. Sacramento, Calif.: 2006.

[13] Reuters. "DVR-Equipped Set-top Box Shipments Contract 20 Percent Year-over-Year in the First Quarter of 2009, According to Dell'Oro Group." *Reuters Business Wire*. June 8, 2009.

[14] Reuters. "Profit Rises at Best Buy, but Margins Are a Worry." *New York Times.* December 15, 2009.

[15] U.S. EPA. ENERGY STAR *Summary of Consumer Electronics Programs*. September 2010. Available at http://www.energystar.gov/ia/partners/downloads/SummaryConsumerElectronicsPrograms.pdf.

Reconciling National and Local Policy Objectives on Energy Efficiency in the United States

Dr. Hossein Haeri, Eli Morris, and Dr. Tina Jayaweera

The Cadmus Group, Inc

Abstract

In the United States, several independent entities play a role in promoting energy efficiency. The federal government sets equipment efficiency standards and provides funding for certain initiatives. State and local governments establish building codes and utility conservation targets, while utilities and other agencies, such as state governments and third-party implementers, administer programs. While these entities share the common goal of increasing efficiency, their objectives differ and occasionally compete. Whereas federal and state regulations are driven by broad-based concerns such as energy independence and reducing greenhouse gas emissions, utility concerns tend to be local, focusing on meeting future resource requirements, protecting shareholder interests, and the potential impacts of program spending on utility rates.

Introduction

This paper focuses on the challenges that the structure of multiple independent entities involved in promoting energy efficiency creates for utility planning. In particular, how changes at the federal and state level can create uncertainty in utilities' energy-efficiency program planning, particularly in states where energy efficiency performance standards are in effect. To illustrate the point, this paper analyzes the residential general service lighting standards established in the U.S. Energy Independence and Security Act of 2007 (EISA), focusing in particular on the effect they will have on utility sales forecasts, energy-efficiency programs, and ability to meet state-mandated savings targets. Starting in 2012, EISA mandates minimum lighting efficacies that represent a 30 percent reduction over incandescent technology. This legislation is particularly problematic for planning purposes for two reasons: 1) Equipment at the minimum required efficiency is not widely available and it is unclear if CFLs will become the *de facto* standard and 2) CFLs have historically represented a large portion of utility energy-efficiency program savings, requiring programmatic adjustments to maintain or achieve the high level of conservation, as may be required by state mandates. To begin, we will look at sources for conservation in the United States, then describe the implications of EISA, and finally provide a case study of Pennsylvania where recent state mandates have set utility conservation targets.

Sources of conservation

Advances toward energy efficiency in the United States generally originate from two overarching sources: energy savings acquired through programs sponsored by utilities or third-party, non-governmental organizations (NGOs) and efficiency gains from other, "non-programmatic" means.

Savings from programs offered by utilities or other organizations

Many public and investor-owned utilities in the United States sponsor energy-efficiency programs, which offer incentives to customers who install certain high-efficiency measures, such as energy-efficient appliances or insulation. These incentives are typically monetary rebates, offsetting all or part of the incremental cost of the upgrade. If the cost of conserved energy is lower than the cost of generating and supplying the energy being offset, the program is considered "cost-effective." Cost-effectiveness is generally a requirement at the portfolio and/or program level, but certain programs (e.g. programs targeted at low-income populations) may be exempt from this requirement. Because utilities can implement these programs to offset future load growth and energy generation requirements, program savings goals become a critical element of resource planning and load forecasting.

In many states, legislatures and/or regulatory commissions have established energy savings targets for utilities to meet through their energy-efficiency programs. These energy savings targets are most commonly determined as a percent of retail sales. In addition to energy-savings requirements, some states require one or both of the following:

- Budget caps – Maximum allowable spending on energy efficiency programs, typically calculated as a percentage of retail revenues.
- Peak demand savings – Minimum demand reduction in system peak periods as a result of the energy savings. This requires that utilities include measures which will have significant impacts during peak periods (summer or winter, depending on the jurisdiction), rather than simply base load measures.

Non-programmatic savings

In addition to programmatic savings described above, conservation may also occur through non-programmatic channels. These include: energy-efficiency standards, building codes, market transformation, and market-induced adoptions.

Equipment-efficiency standards

Efficiency standards specify the minimum efficiency level of energy-consuming equipment that can be manufactured and/or purchased by consumers. These standards are typically established by the federal government, but can also be mandated by state or local governments. The impact of these standards on future energy consumption can vary greatly in magnitude, depending on the scope and applicability of the standard. In some cases, these standards may merely formalize current standard practices, while in others they represent substantial improvements in equipment efficiency over standard practices (e.g. the increase of minimum central air conditioner efficiency from SEER 10 to SEER 13 in 2006 in the United States).

Building codes

Building energy codes, generally established by state or local governments, set minimum guidelines for building characteristics, applicable to new construction and major renovations, affecting the level of energy consumption in these facilities. These codes may inform energy consumption directly (e.g. lighting power density in commercial facilities) or indirectly (e.g. minimum insulation levels). Many jurisdictions in the United States have adopted the International Energy Conservation Code (IECC) as the building energy code, although not every state has a state-wide energy code.

Market transformation

Market transformation is a means of changing the market by indirectly affecting common practices. In other words, encouraging many manufacturers to produce a large selection of high-efficiency refrigerators will increase the likelihood of these refrigerators being installed and thus eventually make them become the new baseline. These programs often work in conjunction with utility programs, but are often promoted through separate agencies. A prime example of market transformation agency is the ENERGY STAR® program. ENERGY STAR, a joint venture of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE), sets requirements for rating efficient equipment. These specifications do not set minimum efficiency standards, rather provide guidance on which equipment should be considered “efficient”, thus facilitating the inclusion of such technologies in energy-efficiency programs. ENERGY STAR-qualified equipment is generally 10 or 15 percent more efficient than the federal standard, if such a standard exists.[1] The ENERGY STAR Label provides the consumer an easy way to identify and purchase energy-efficient products without a sacrifice on performance or quality [1]. The existence of this standard also facilitates inclusion of such technologies in energy efficiency programs.

[1] One example of ENERGY STAR setting a standard where no federal standard exists is in televisions. ENERGY STAR sets limits on power consumption for televisions, based on market average.

Market-induced adoption

Market-induced effects refer to the non-programmatic adoption of energy-efficient technologies and practices, motivated by higher energy prices, tax credits or government spending, macro-economic conditions, or shifts in cultural norms (e.g. “green movement”). These savings reflect the adoption of energy-efficient technologies in the marketplace, excluding those associated with codes and standards or utility program incentives.

Figure 1 illustrates how the various channels build toward energy conservation.

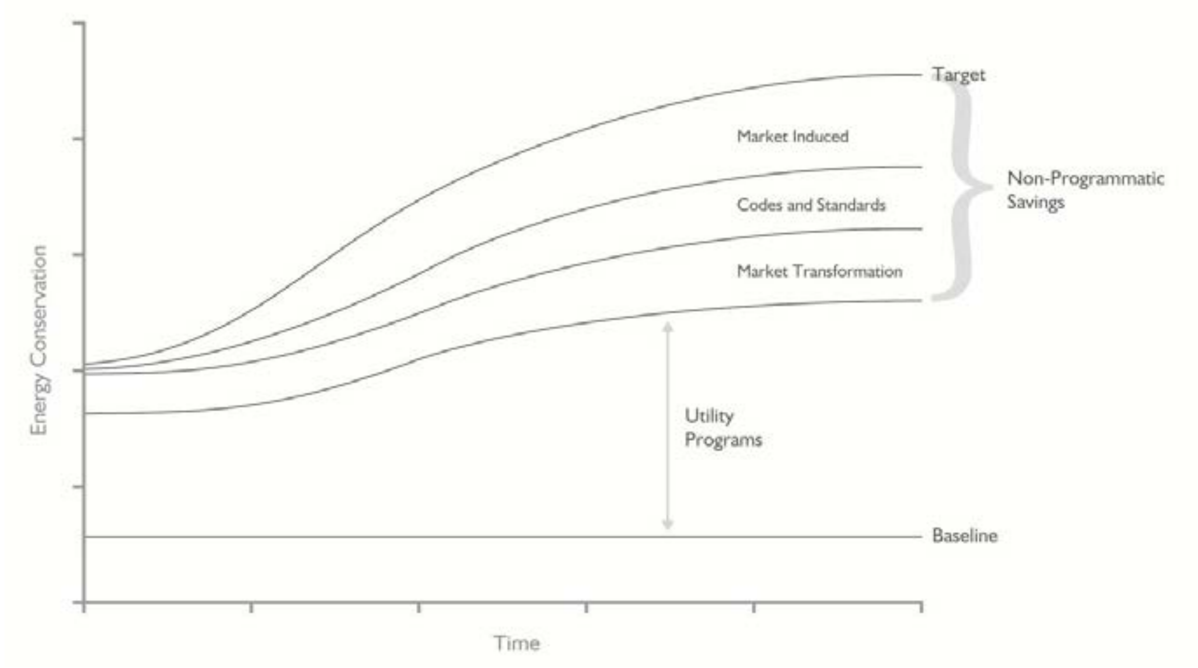


Figure 1. Sources of Savings

Clearly, the various means of improving efficiency listed above are not mutually exclusive and, given that the amount of available energy savings is finite, energy savings from one of these sources will affect the amount available to the others. While there are interactive effects between any combination of two or more of these mechanisms, this paper focuses on the interaction between federal efficiency standards and utility planning, illustrated by recent standards regarding general service lighting.

Residential General Service Lighting Standards in the Energy Independence and Security Act of 2007

In December 2007, the United Sates Congress passed a bill, known as the Energy Independence and Security Act of 2007 [2] (EISA) which, among other provisions, set new standards for energy efficiency for a number of end uses. Perhaps most notably, EISA mandates higher efficiency levels for general service light bulbs sold in or imported into the United States beginning in 2012, phased in by wattage range. As shown in Table 1, EISA’s performance standards correspond to approximately 30 percent improvements in efficacy (measured in lumens-per-Watt) over current incandescent technology.

Table 1. EISA Requirements for General Service Incandescent Lamps

		EISA Requirements		
Lumen Output	**Typical Wattage of Current Incandescent Technology**	**Maximum Wattage**	**Minimum Lifetime (hours)**	**Effective Date**
1490–2600	100	72	1,000	1/1/2012

1050–1489	75	53	1,000	1/1/2013
750–1049	60	43	1,000	1/1/2014
310–749	40	29	1,000	1/1/2014

The Act includes an additional "backstop" provision requiring efficacy to reach near-CFL levels by 2020. It is important to note EISA is a performance-based standard; thus, standards are "blind" to technology and do not ban incandescent bulbs.

At this point, it remains unclear what the effect of these standards will be. Currently, CFLs are the only widely available and accepted technology meeting the prescribed efficacy levels; however, by 2012, there may be other options meeting the requirements. This uncertainty leads to two possible baseline scenarios:

1. ***EISA Minimum Scenario***. While EISA will preclude current incandescent technology, advanced incandescent bulbs can meet EISA's minimum standards. Advanced incandescent bulbs currently exist; however, these bulbs currently cost more than a comparable CFL, and it is unknown how much the price might drop in the next few years. If the cost decreases and quality is similar to current incandescent bulbs, these may become the preferred choice for most customers. In this scenario, potential from CFLs would remain until 2020, though the savings would be reduced by about one-third from current levels due to a more efficient baseline technology.
2. ***CFL Baseline Scenario***. If the technology described above does not become viable by the time the standards take effect, CFLs could become the *de facto* baseline, meaning that although CFLs are more efficient than minimum requirements, they will be the only viable technology, and customers' primary option for lighting.

It is important to note that neither of these scenarios completely eliminates potential savings in residential lighting. In addition to measures such as occupancy sensors, there will still be an opportunity for lighting with higher efficacy than CFLs, such as LEDs. Currently, though LEDs offer longer lifetimes and higher savings than CFLs, the up-front cost is significant, and questions remain regarding the quality of light. However, over the next several years, LEDs could become a viable option for savings beyond CFLs.

The Effect of EISA on Utility Planning: Pennsylvania Case Study

From the two baseline scenarios described above, it is clear that there is a large amount of uncertainty around the impact of the EISA standards on utility sales and energy-efficiency program savings. To illustrate the potential impacts, this paper presents a case study based on the state of Pennsylvania.

Utility Sales Forecasts

According to the U.S. Energy Information Administration's (EIA's) 2011 Annual Energy Outlook [3] (AEO11), the residential sector accounts for about 37 percent of 2010 electricity consumption in the Middle Atlantic census division, of which Pennsylvania is a part. While AEO11 does not report end use consumption by census division, it does estimate that nationally, lighting is estimated to represent roughly 15 percent [4] of residential electricity consumption. Multiplying these two estimates together indicates that residential lighting likely represents around five percent of total electricity sales in the state.

A 2009 study conducted by the American Council for an Energy-Efficient Economy (ACEEE) estimated that statewide electricity sales would grow from 151,177 GWh in 2007 to 188,217 GWh in 2025 [5]. Assuming the distribution of sales by sector and end use is held constant over this period, this would equate to about 9,400 GWh of residential lighting consumption, in the absence of EISA. While this is a relatively small percentage of total sales in Pennsylvania, it is larger than the total 2008 statewide consumptions of Vermont, Alaska, and Rhode Island [6].

Pennsylvania's Act 129

On October 15, 2008, Pennsylvania Governor Ed Rendell signed House Bill 2200 into law as Act 129 of 2008 (the Act). The Act imposes new requirements on electric distribution companies (EDCs), with the overall goal of reducing energy consumption and demand. On January 16, 2009 the Pennsylvania Public Utility Commission (the Commission) issued an Implementation Order (the Order), clarifying the requirements of the Act and outlining a procedural schedule for compliance [7]. As outlined in the Order:

"This program requires an EDC with at least 100,000 customers to adopt a plan, approved by the Commission, to reduce electric consumption by at least one percent (1%) of its expected consumption for June 1, 2009 through May 31, 2010, adjusted for weather and extraordinary loads. This one percent (1%) reduction is to be accomplished by May 31, 2011. By May 13, 2013, the total annual weather-normalized consumption is to be reduced by a minimum of three percent (3%). Also, by May 31, 2013, peak demand is to be reduced by a minimum of four-and-a-half percent (4.5%) of the EDC's annual system peak demand in the 100 hours of highest demand, measured against the EDC's peak demand during the period of June 1, 2007 through May 31, 2008."

In addition to these energy and demand reduction mandates, there are also provisions regarding budgetary limits and program offerings to government and low-income markets. In response to the Order, each EDC filed a plan detailing program offerings from 2009 through 2013, expected budgets and energy and demand reductions.

Utility Energy Efficiency Programs

Historically, residential lighting has accounted for a disproportionate share of energy efficiency program savings relative to its share of total sales. CFLs are widely commercially available, extremely cost-effective when compared to supply-side resources, and relatively easy to deploy through incentive-based or upstream buy-down programs. This is particularly true for utilities with little or no experience running energy-efficiency programs, as they may not yet have established the infrastructure necessary to aggressively pursue other markets. As such, utilities have relied heavily on CFLs to help offset load growth and meet aggressive mandated energy-efficiency goals.

All Pennsylvania EDC plans included a residential CFL program [8]. Each plan also included a non-residential HVAC and lighting program with some CFLs, although the majority of non-residential lighting savings will come from linear fluorescents. Statewide, residential CFLs are expected to account for about 15 percent of total portfolio savings, ranging from 2 percent to 22 percent for individual EDCs.

While the percent of portfolio savings from CFLs varies greatly across EDCs, the 15 percent statewide figure represents a substantial amount of savings (750 GWh, cumulative in 2013). This poses several potential future problems for EDCs. While savings targets beyond 2013 have not yet been established, it is likely they will be comparable to or higher than current levels. If EDCs are no longer able to claim savings from CFLs (or if only savings above EISA minimum standards can be claimed), a substantial amount of current portfolio savings will need to be acquired elsewhere.

CFLs are one of the most cost-effective resources available, and, to acquire savings elsewhere will most likely require substantial additional spending. In the 2009 plans filed by one of the state's two largest utilities, CFL programs accounted for approximately 21percent of total portfolio savings, but expected to require only 5 percent of the total portfolio budget. Given the budget constraint imposed by mandated expenditure caps, the shifting of the required savings to higher-cost resources, would increase the overall cost of implementing the plan by 18 percent, making it difficult, likely impossible, for EDCs to reach their mandated targets within spending limits.

Conclusion

Recent concerns in the United States about energy security and independence have prompted many legislative and regulatory bodies to establish aggressive energy-efficiency performance targets for utilities. These targets, coupled with the decentralized decision-making regarding alternative strategies for improving energy efficiency, have confronted regulated utilities with the formidable challenge of achieving energy-efficiency targets under increasing uncertainty arising from factors beyond their immediate control. Aside from a more coordinated approach to a nationwide strategy for energy efficiency, it is important to consider more flexible energy-efficiency performance standards with explicit provisions for accounting for non-programmatic changes in efficiency. Ideally, such provisions would clearly spell out how such changes would factor in utility targets.

References

[1] ENERGY STAR http://www.energystar.gov/index.cfm?c=home.index

[2] United States Energy Independence and Security Act of 2007 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

[3] United States Energy Information Administration, *2011 Annual Energy Outlook Early Release*, Table 4, December 2010. Can be downloaded at: http://www.eia.gov/oiaf/aeo/supplement/suptab_2.xls

[4] United States Energy Information Administration, *2011 Annual Energy Outlook Early Release*, Supplemental Table 2, December 2010. Can be downloaded at: http://www.eia.gov/forecasts/aeo/excel/aeotab_4.xls

[5] American Council for an Energy-Efficient Economy *Potential for Energy Efficiency, Demand Response, and Onsite Solar Energy In Pennsylvania*. April 2009.

[6] United States Energy Information Administration, Energy Consumption by Source and Total Consumption per Capita, Ranked by State, 2008. Can be downloaded at: http://www.eia.doe.gov/emeu/states/sep_sum/html/pdf/rank_use_per_cap.pdf

[7] Pennsylvania Public Utility Commission http://www.puc.state.pa.us/electric/Act_129_info.aspx

[8] GDS Associates, Inc. Audit Plan and Evaluation Framework for Pennsylvania Act 129 Energy Efficiency and Conservation Programs, December 2009. Can be downloaded at: http://www.puc.state.pa.us/electric/pdf/Act129/SWE_Presentation-Audit_Plan120109.pdf

Combining theoretical and empirical evidence: Policy packages to make energy savings in appliances happen

Lena Tholen, Dr. Stefan Thomas

Wuppertal Institute for Climate, Environment and Energy

Abstract

What are the best policies and measures to stimulate energy efficiency in residential appliances, heating, ventilation cooling and lighting? The debate on this is at least as diverse as the markets and concepts for energy efficiency in these areas, and is often discussed quite controversially. However, no magic formula seems to have been found so far. It is, therefore, time to bridge the information gap and address the question in a new way - by combining both theoretical evidence on what policy support markets need, and empirical evidence on the combinations or packages of policies which have worked.

In the context of its new four-year project bigEE – "Bridging the Information Gap on Energy Efficiency in Buildings" – the Wuppertal Institute is implementing this new approach. The bigEE project aims to develop an international internet-based knowledge platform for energy efficiency in appliances, buildings, and building-related technologies. Hence, it must provide evidence-based information.

On the theoretical side, the analysis starts with value chains in the appliance sector and the barriers but also market-inherent incentives of the different types of market participants. Empirical evidence will feed the collection of these barriers and incentives. This enables to identify, which policies and measures need to be combined to jointly overcome the barriers and strengthen the incentives.

On the empirical side, model examples of good practices are collected and compared. The search for these policy packages or single instruments is guided by the results of the theoretical analysis. A network of international experts and existing databases and platforms is also giving information for the search. In order to identify what is "good practice" among the examples collected, the project uses a newly developed multi-criteria assessment scheme, which is presented in this paper. The assessment scheme is tested by a successful policy to demonstrate the procedure of the assessment scheme.

Finally, the impacts achieved with the model examples, lessons learned from their implementation, and their transferability shall be used to validate the different factors which are necessary to implement a successful policy and which were identified in the theoretical analysis.

Introduction

Energy efficiency has major potentials for innovation and market opportunities and should therefore be supported by adequate policies and measures. Decision makers already recognised energy efficiency as a key element for progress towards a more sustainable energy future, with high potentials and advantages for their own country. Consequently, the topic has been on the policy and business agenda for years, with significant achievements already made in several countries worldwide.

A main topic for energy efficiency in the residential sector is the electricity consumption of residential appliances like refrigerators, TVs or washing machines. To implement a policy that strives towards energy efficient products and to minimize the use of electricity, decision makers must have good knowledge of the respective sectors concerned, in order to be able to adequately implement a successful policy.

The question remains: What are preconditions for a successful policy and which criteria are crucial to consider? What must a criteria scheme look like to decide about the success of a policy and measure? The new project bigEE – “Bridging the Information Gap on Energy Efficiency in Buildings” – tries to answer these questions and summarises several concepts to fill this information gap and thus attempts to create a new and comprehensive approach. The aim is to detect all relevant factors, which are needed to develop a successful policy and further to make these factors visible to policy makers worldwide. They have the chance to use this knowledge as basic information and thus implement a policy with a well-grounded theoretical and empirical background.

With the presentation of knowledge based on already established experiences and research efforts, the bigEE project aims to increase the energy efficiency level of appliances worldwide and to promote policy options for decision makers to achieve this goal. This paper concentrates on the policy side. A focus is put on the connection between theoretical and empirical evidence and the question how established theoretical options fit together with experiences gained from already implemented policies and measures. Due to the focus of the EEDAL conference, this paper focuses on the identification of policy options for increasing the energy efficiency of residential appliances.

In the following chapters, the bigEE project will be briefly described to illustrate the project background and scope. Afterwards the ’ideal’ policy package in the appliance field, which is known in principle with its various policy instruments and the interactions between single policy instruments will be presented. It is now widely accepted that a policy package can achieve the greatest success, given that a large variety of barriers and market failures exist, which hinder a rapid market change towards higher energy efficiency in appliances.

The bigEE project tries to validate this ‘ideal’ policy package and address the question of how energy efficiency can be supported most effectively – by combining a theoretical, actor-centred analysis with empirical evidence on model examples of good practice policies. By closely analysing the actors in the value chains and their incentive structures and then deducing implementation strategies and ideal policy packages, this paper aims to provide a solid methodological basis for the often-quoted necessity to implement comprehensive policy packages. The methodological approach, which will be presented in the following chapters, is based on and seeking to extend and refine the theory-based policy evaluation approach, which goes back to US experiences with energy efficiency policy evaluation (e.g. [1]) and was applied and developed further more recently within the EU project AID-EE [2]. In the second part, the paper compares the outcome of this actor-centred analysis with empirical evidence on policy instruments that have actually worked and delivered significant energy savings. In this context, a newly developed multi-criteria assessment scheme will be presented to identify good practice policies. One briefly outlined model example illustrates the empirical evidence for a successful policy option that could be part of an ‘ideal’ policy package.

Due to space constraints, this paper can only present an extract of the full analysis, which will be made available by the time of the EEDAL ’11 conference at www.bigee.net.

Bridging the information gap on energy efficiency in buildings

It is widely accepted that energy efficiency is the biggest, fastest, and most cost-effective option for saving energy and mitigating climate change, with at least 40% of the energy efficiency potential in appliances and buildings [4]. Yet, both investors and policy-makers are still far from fully tapping this potential, even if abundant information on good practice technologies and policies is in principle available. However, the information is scattered, too little tailored for specific target groups, and not easy to find for decision-makers. Thus, the information and implementation gap is still large, both in the market and with policy-makers.

This is why bigEE – “Bridging the Gap on Energy Efficiency in Buildings” – the new project by the Wuppertal Institute, with financial support from the German government, aims to develop an international internet-based knowledge platform for energy efficiency in appliances, building-related technologies and buildings overall. The platform will address the needs of decision-makers in businesses and policy; a structured presentation will make it easy to find the information wanted. Primary target groups of the initiative are policy-makers, public and private investors, and actors and consultants in policy and energy service implementation.

Apart from information universally applicable, up to five partner countries will be addressed, starting with China and India. A central task for bigEE is collecting, making comparable and updating information on “best available technologies”, energy saving potential, net economic benefits, and good practice policies. To achieve the required quality of information, the bigEE team collaborates with scientific institutes – international and in partner countries, with existing initiatives – international and in partner countries, with existing initiatives and platforms, and the Sustainable Buildings Network (SBN) under IPEEC. Furthermore, bigEE engages in the active dissemination of information relevant for investors and policy makers in the partner countries, by setting up and cooperating with a network of local partners.

The summarised objectives of the bigEE project are:

- Raise greater awareness and attention for the variety of benefits of increased energy efficiency in new and existing buildings and residential appliances.
- Close the gaps of scattered information and material on energy efficiency by providing latest know-how in a target group oriented, consistent, easily accessible, and transparent way.
- Manage and communicate available knowledge especially for emerging economies.

Figure 1 gives an overview about the bigEE topics. The project aims at two parallel knowledge fields: The technological potentials and the policy options to increase energy efficiency. The column with the title “EE Policies” on the right side of the figure sets the framework for the contents of this paper.

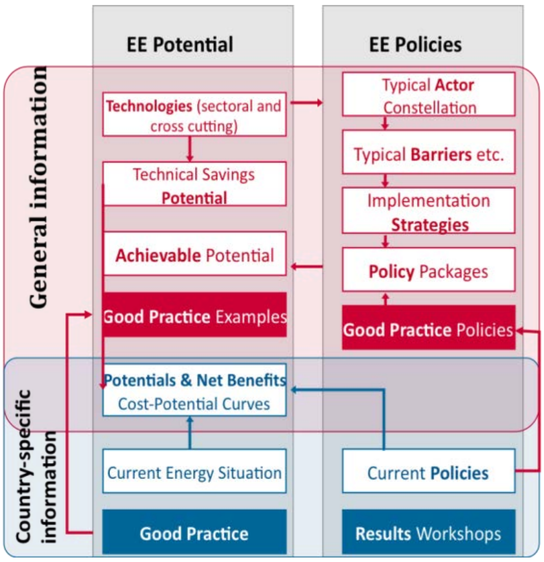


Figure 1: The bigEE project - overview

The ‘ideal’ policy package for appliances

The bigEE project pursues a web-based presentation of energy saving potentials and good practice policies and policy combinations for buildings and appliances worldwide. The objective of this paper is to present how the project attempts to find these ideal packages and good practice policies. According to international research and experience, a package of several types of consistent and technology-specific and actor-specific policy instruments is useful to be most successful. Instead of a single instrument, a package offers the opportunity to achieve synergies between single instruments, and to reach all market actors [6].

Every policy measure has its own advantages, ideal target groups and specific operational mechanisms. Each is tailored to overcome one or a few certain market barriers, but none can address all barriers. Most instruments achieve higher savings, if they operate in combination with other measures, and often these impacts are synergistic, i.e. the impact of the two is larger than the sum of the individual expected impact [3]. Therefore, the ideal policy consists of consumer-oriented instruments and instruments for manufacturers (to build a "push and pull strategy" to push consumers and manufacturers away from energy intensive practices and to pull them towards energy efficient ones). Several instruments exist worldwide with the aim to increase the energy efficiency of appliances. For energy efficiency in appliances, these instruments can be packaged as follows:

Legal provisions on minimum energy performance standards (MEPS) reduce search and transaction costs and partly overcome the investor-user dilemma. They are a cost-effective way to at least eliminate the worst energy-performing products from the market. However, they do not harness additional savings potentials due the most energy-efficient products in such cases. Therefore, appliance standards are often combined with labelling and rebates in order to give incentives for investments beyond the level required by the minimum energy efficiency standard. On the other hand, labelling programmes cannot completely transform the market and, for this reason are completed by MEPS in the great majority of countries [7]. To pull the market even more into an energy efficient direction, information programmes, trainings for sales staff and manufacturers, and especially procurement programmes can influence the market to promote energy efficient appliances. Figure 2 illustrates an ideal policy package for appliances and describes the interactions between minimum energy performance standards, energy labels, rebate schemes, market and technology procurement, and information and training programmes.

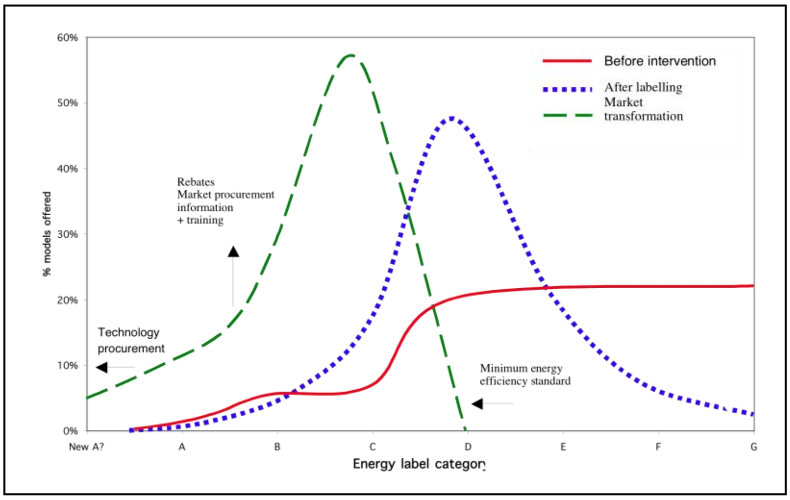


Figure 2: Policy package for domestic appliances

Source: Wuppertal Institute, partly adopted from DECADE (1997)

In order to prove this hypothesis of an ideal policy package that includes push and pull strategies, reaches all relevant market actors, and moves the market towards the most energy efficient appliances, the bigEE project uses a combination of theoretical and empirical evidence. The aim of this paper is to only present the scientific approach with few examples. The approach, and the paper as well, is divided into two parts: The first step is a theoretical, actor-centred analysis which is in a second step combined with an empirical evidence on model examples, i.e. already implemented good practice policies. The full actor-centred analysis can be found at www.bigee.net; the empirical evidence will be added there later.

Theory-based, actor-centred analysis

Different steps are needed to derive an 'ideal' policy package, which increases the energy efficiency of appliances. The refined actor-centred approach can be subdivided into several steps. It starts with the identification of all relevant market actors along the value chain of the national market for the type of appliance concerned. In order to be able to adequately design and implement energy efficiency policies and measures, political decision makers must have good knowledge of the concerned market actors and thoroughly analyse the specific incentives and barriers faced by each of them. As a next step, implementation strategies to overcome the identified barriers and to strengthen the incentives need to be developed. Then, policy instruments to materialise these implementation strategies must be discussed; usually already a package of individual policies and measures needs to work together to implement one strategy. The final step is the combination of these strategies and their respective policies to create market-adapted overall policy packages with the adequate combination of policy instruments.

In a further step, this theoretical approach will be combined with an empirical proof. In the second part of this paper one single instrument will be described and analysed as an example for a part of an effective policy package. This example - a financial incentive programme – was not only successful as a single option but especially as a part of a package consisting of MEPS, labels and soft measures like training and educational programmes.

Market actors and specific barriers and incentives

Before creating a policy to increase the energy efficiency of residential appliances, it is essential to have a closer look at all relevant market players along the value chain and their actor-specific market-inherent barriers and incentives to manufacture, sell, or buy an energy-efficient product. The list below illustrates key actors on the supply side, on the demand side, and further actors [6]. They may be more or less relevant on a national market, but for our analysis to be valid in general, we have included all of them.

<u>Actors on the supply side</u>

- Manufacturers and importers of appliances which are sold to end-users or which are sold to downstream manufacturers or installers; component manufacturers
- Wholesalers, retailers and sales staff in retail companies

<u>Actors on the demand side</u>

- Investors in energy efficiency who are users of the energy-efficient appliances at the same
- Investors in equipment who do not use the technology themselves
- Users of appliances who are not, at the same time, investors in energy efficiency

<u>Political institutions and further actors</u>

- National and sub-national or supra-national parliaments, governmental bodies and administrations
- Energy consultants and energy agencies
- (environmental) NGOs, consumer organisations, trade associations

After identifying the relevant actors in the appliances market, it is necessary to put the focus on the actor-specific barriers and incentives. Each actor group has its own characteristics and therefore every policy has to pay attention to these. By knowing the barriers and incentives of every actor the policy package can be adapted to guarantee desired results and achieve the greatest possible success. bigEE has developed extensive tables looking at all relevant actors. The following table presents just an extract.

Table 1: Actor specific barriers and incentives

Target group	Barriers	Incentives
(Component-) Manufacturers	- Prevailing price competition or predominance of other product features over energy efficiency - Risk of technical development: Will	- Increased direct earning of profits for actors on the supply side: The energy-efficient option usually requires higher upfront investment

	there be a market for energy-efficient appliances? - Risk of production and marketing: Will there be a sufficient demand? - Lack of knowledge about the market situation - Lack of knowledge about technical options - Uncertainty about availability of sufficient quantities of reasonably priced components	by the buyer. From a supply perspective, this means higher prices/revenues and possibly higher profits (if customers are willing to pay more due to the expected energy cost savings) - Offering energy-efficient solutions can act as a unique selling proposition and thus lead to competitive advantage of even market leadership - Both end-users and the environment benefit from energy-efficient solutions: Offering such solution thus underpins a company's CSR goals - Offering higher value to the customers
Investors in energy-efficient appliances who are also their users	- Low energy costs/low savings/other economic priorities - Lack of motivation - High search and transaction costs - Reluctance/sceptism towards new products and technologies from new suppliers/companies - Lack of capital - Uncertainty about future energy prices - Lack of knowledge about efficient technology - Insecurity about continuity. What will be in 5, 10, .. years - High profitability requirements - Misleading price signals due to rate design and lack of internalization of external costs - Risk aversion: Does the new technology guarantee the same level of functionality and security? - Other functional priorities - Habits, good experiences	- Save energy costs: The energy-efficient product is often the cost-effective solution - Increase (re-sale) value of the appliance - Contribution to environmental protection - Receive social recognition in return for environmentally-sound behaviour
…	…	…

The identified barriers and incentives create one question: How can these barriers that market actors face be overcome and how can the immanent incentives be strengthened? The described barriers are the major reason why there is a gap between potential and realised energy savings. That is why policy makers have to identify these barriers to overcome them and to strengthen the market inherent incentives for energy efficiency. A number of ways to achieve this are available. The following chapter summarises some of these strategies and describes them briefly. The aim is to make energy efficiency feasible, easy, attractive, and eventually even the default.

Implementation strategies and policy packages

A number of direct ways to reach the relevant actors, tackle their barriers and strengthen their incentives, and thus to maximize the energy savings exist. These ways can be named implementation strategies. An implementation strategy may act on several incentives and barriers. An example for an implementation strategy is: "*Bring down the first costs of energy-efficient appliances via market* *transformation/economics of scale*". This example picks up economic aspects and tries to overcome financial barriers and strengthen financial opportunities. The economic barrier is only one example for several other barriers and corresponding implementation strategies. The next table summarizes this example of an implementation strategy with the actor-specific barriers it tackles and incentives it strengthened.

Table 2: An example for an implementation strategy with corresponding barriers tackled and incentives strengthened

Implementation strategy	Barriers tackled	Incentives strengthened
Bring down the first costs of energy-efficient appliances via market transformation/ economics of scale	(Manufacturers) Extra construction costs: risk of loosing customers to the competition (assuming that customers look at first cost only). (Investors, users) Lack of motivation because savings are too small, uncertainty about level of benefits and costs (is it worth it?), other priorities etc. (Investors, users) Present-biased preferences, uncertainty about ability to reap the benefits, excessive expectations in terms of payback. (Investors, users) Lack of capital real or perceived costs, innovations only with short payback period. (Manufacturers, wholesalers, retailers) Prevailing price competition or predominance of other product features over energy efficiency; therefore low priority by manufacturers and low willingness to pay (more) for energy-efficient products. (Investor ≠ users) No direct economic advantage for cost effectiveness.	(Investors) Save energy costs. The energy efficient product is often the cost effective solution (Investor ≠ user, manufacturer) Increase value of the property; from a supply perspective, this means higher revenues and possibly higher profits. Justification for higher prices (Manufactures, users) Contribution to protection of the environment

The next step is to find an adequate policy package to realise the implementation strategies and to guarantee lasting effects. It is essential to have a look at the technology and the product-specific potentials and to demonstrate the best way how to increase energy efficiency with a package of different but coordinated instruments.

To come back to the financial oriented implementation strategy presented in table 2 and addressing certain actor-specific barriers and incentives, the following policy instruments are options to bring down the first costs of energy-efficient appliances: economic incentives like grants, subsidies, rebates, soft loans, and innovative financing schemes such as on-bill financing, functional services or 'pay as you save' schemes for very efficient new products. In addition, a support on how to find and apply these financial options is essential to be successful. Other measures to reduce the first costs are tax rebates and public or technology procurement programmes. The target group for these measures are (directly and indirectly) manufacturers, end-users and investors in energy efficient appliances.

Some instruments are alternative to each other, but usually several instruments should be coordinated in an adequate policy package to establish synergy effects and realise the implementation strategy. The implementation strategy mentioned for tackling economic barriers and incentives is only one example of several other implementation strategies and their respective policies and measures. The ideal package to realise all the needed implementation strategies will be illustrated on the project related website www.bigee.net. In general, we conclude that our actor-centred analysis has confirmed the 'ideal' policy package presented above but lack the space to demonstrate the final steps in this paper.

The empirical proof: policies and measures used by successful countries

To create successful policy packages and to guarantee lasting results single policies and measures must be successfully implemented and coordinated with other policies which were already implemented. An effective policy package consists of several innovative and successful P&Ms.

Numerous programmes to promote the energy efficiency of appliances exist. For example, minimum energy performance standards and voluntary or mandatory labelling schemes were already implemented in many countries worldwide (overview: see inter alia www.clasponline.org or www.iea.org). Furthermore, financial incentive programmes and awareness-building measures were implemented in many countries in addition to regulatory instruments to lead consumers to buy the most energy-efficient products. Nevertheless, full analytical assessments which of these strategies and instruments were most successful are not available until now. The first part of this paper dealt with the actor-centred theoretical analysis and the development of implementation strategies and policy packages to increase energy efficiency.

For the verification of the described theoretical approach and the resulting 'ideal' policy package, policies already implemented in different countries will be analysed in the bigEE project to find out, which preconditions are necessary to name a policy a "good practice example", and to create the basis for a successful policy package that consists of several well implemented policies. Consequently, a method how to find good practice policies is necessary. A new multi-criteria assessment scheme was developed to rate policies and measures and to judge whether a policy was successfully implemented and can be named a good practice policy or not.

Criteria to rate the policy instruments

To evaluate, compare and decide which policy or policy combinations have worked best and can be called 'good practice', the Wuppertal Institute developed a new multi-criteria assessment scheme. The function of the assessment scheme is to compare policies and to highlight worldwide good practice policies. A comprehensive system to rate policies and measures has the chance to demonstrate success factors and potentials (energy savings, cost-effectiveness etc.). The aim is to present good practice examples to policy makers and to provide incentives to transfer these policies (especially to emerging countries).

The scheme is based on ten criteria. Main criteria are the already mentioned integration of all relevant market actors and the analysis of existing barriers and incentives. The ideal policy addresses all market players and barriers, avoids lost opportunities and lock-in effects, has dynamic efficiency levels, lasting results and spillover effects. Other aspects are the innovative structure of the policy or the policy package and the promotion of high energy efficiency standards (according to the best available technology or the least life cycle costs). The policy must have been evaluated to be a model example. The calculated cost-effectiveness and the achieved high energy savings (per unit and overall) demonstrate the successful implementation. Finally, the measures should not have significant negative side-effects like rebound effects, snap-back effects and free-rider effects to be ranked as good practice policy.

Table 2 shows this multi-criteria assessment scheme for good practice policies. Next to the ten selection criteria, the operationalisation is described and the weight for the selection is presented. The assessment scheme differentiates between proven policies, which are already in place for several years, and innovative policies, which were implemented short time ago. Some of the selection criteria require a ranking between 0 and 10. This ranking will play a role in the overall assessment of the policy and during the decision whether the policy can be named good practice policy. The comments on the right side give some explanatory remarks.

Table 3: Multi-criteria assessment scheme for good practice policies or policy packages

<table>
<tr><th rowspan="2">No</th><th rowspan="2" colspan="2">Selection Criteria Good Practice P&M</th><th rowspan="2">Operationalisation</th><th colspan="2">Weight for selection</th><th rowspan="2">Comments</th></tr>
<tr><th>P&M with proven effective-ness</th><th>Innovative P&M</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2" colspan="2">The policy has been successfully and durably implemented into the market</td><td>Implemented</td><td>Eligibility</td><td>Eligibility</td><td>P&M is or was in force at least in one country and provides preconditions which are in principle transferable to other countries</td></tr>
<tr><td>At least 2 years in place before date of website publication</td><td>Eligibility</td><td>n/a</td><td>P&M is or was in force at least in one country</td></tr>
<tr><td>2</td><td colspan="2">Recent P&M</td><td>Not older than 10 years before date of website publication</td><td>If not, justification required</td><td>If not, justification required</td><td>Last revision date of the P&M counts</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">Appropriate design of P&M</td><td>Addresses all relevant market actors and most relevant barriers and incentives</td><td rowspan="5">Ranking as a whole on a scale between 0 and 10</td><td rowspan="5">30%</td><td rowspan="5">40%</td><td>Often better achieved when policy is part of a package</td></tr>
<tr><td>Is designed to avoid lost opportunities</td><td>For example, addresses the energy-efficient solutions in the right manner and moment, e.g., by taking into account the investment cycle of the target group</td></tr>
<tr><td>Aims at dynamic market transformation</td><td>For example, promotes innovations to make BAT even more energy-efficient, and/or, increasingly removes inefficient technology/practices from market</td></tr>
<tr><td>Achieves lasting results</td><td>For example, no snap-back effect</td></tr>
<tr><td>Positive spillover effects should be an objective</td><td>Large multiplier effects</td></tr>
<tr><td>4</td><td colspan="2">Includes innovative P&M elements or combines them to an innovative P&M package</td><td>Ranking on a scale between 0 and 10</td><td>10%</td><td>30%</td><td>Outstanding compared to other countries, e.g.: market actor addressed who is not included in other existing P&M; an innovative way to overcome barriers; innovative package of P&M</td></tr>
</table>

5	Does the P&M foster **worldwide BAT** or country-specific **LLCC solutions**? (whatever is appro-priate in the country)	Close to BAT/LLCC = 10; Substantially different from BAT/LLCC = 0	10%	15%	Dynamic life-cycle cost analysis including typical interest rates??
6	A satisfying **ex-post evaluation** exists	Yes = 10; no = 0	10%	n/a ex-ante data if possible	Ex-post evaluation usually gives more reliable data than ex-ante evaluation
7	The energy savings are **cost-effective** (for consumers and the economy)	Benefit-cost ratios from different perspectives	If no data or not cost-effective, justification required	n/a ex-ante data if possible	Dynamic life-cycle cost analysis including correction factors and typical interest rates
8	**Effectiveness I**: The P&M leads to **energy savings per unit** (per appliance) compared to reference case	Is data on energy savings per unit available? Please give absolute and relative numbers.	Not eligible, if no data	n/a ex-ante data if possible	Expected additional, yearly energy savings in %/year and in kWh/year per unit (per appliance) compared to baseline projections
	Effectiveness II: The **effectiveness** is high: How many % of the energy savings potential available within a specific time frame due to normal investment/refurbish ment cycles in the target area (**region / country**) have been implemented?	Please give absolute and relative numbers (BAT or LLCC vs. reference; including correction factors), and then rank on a scale between 0 and 10.	30%	n/a ex-ante data if possible	For example, at least 30% of the potential has been implemented; or the share of energy-efficient technology has increased considerably; or the price premium on energy-efficient technology has decreased; or a service has saved on average at least 30% of the customers' energy consumption
9	The policy is in line with other **sustainability** criteria	Ranking on a scale between 0 and 10	10%	15%	Other aspects like material efficiency, health or employment aspects taken into account.
10	**Mix of countries / continents**	Final selection of portfolio	Global perspective, mix of countries		

P&M = Policies and Measures; BAT = Best Available Technology; LLCC = Least Life-Cycle Cost; correction factors = factors correcting the gross savings for rebound, free-rider and spill-over effects, as well as to eliminate double-counting between P&M

A model example of a good practice policy

To analyse the feasibility of the multi-criteria assessment scheme, the EnergiePremieRegeling (EPR, energy premium scheme), which was developed in the Netherlands in 2000 is used as an example. The Dutch programme was implemented from 2000 to 2003, aiming at, inter alia the purchase of appliances at the top levels of efficiency and performances by creating favourable conditions for consumers. The programme offered cash rebates for the purchase of higher energy efficiency household appliances, like refrigerators (e.g. in 2002, customers received 50€ for each appliance with energy label A and 100€ for super-efficient A+ appliances; in 2003, only A+ and A++ models were eligible for rebates). Therefore, the target group were buyers and users of residential appliances. The rebates, funded by an energy tax (Regulating Energy Tax; Regulerende Energie Belasting REB) were channelled back to the consumer through the utilities. This so called "ecotax" on electricity and gas was in principle paid by the consumer to the state; but the energy companies collected it. The customers had the possibility to get a rebate paid out by the energy company for specific energy efficiency measures. This ended up, as an example, in 94.4% of the market of washing machines being Class A and higher, i.e. the highest penetration in Europe at that time. The energy companies subtracted these energy rebate payments from their ecotax debt [6].

These first impressions of the programme promise success for the identification of a good practice policy according to the newly created multi-criteria assessment scheme. The next chapter analyses the criteria in detail to decide whether the policy was successfully implemented and can be named a good practice policy.

EnergiePremieRegeling – a good practice policy?

The ten criteria of the assessment scheme will be taken up by the policy example to identify a good practice policy. Firstly the policy was successfully and durably implemented in the Netherlands from 2000 – 2003 and the end of the programme is not longer ago than 10 years. Therefore the EnergiePremieRegeling was successfully implemented and is a recent P&M. The next aspect of the assessment scheme deals with the appropriate design of the policy. The programme aims to avoid lost opportunities by providing financial benefits to buy an energy efficient product. Consumers and investors were successfully addressed to overcome existing barriers and to strengthen incentives. Barriers are for example the lack of capital, low energy savings compared to the costs and the lack of knowledge. Furthermore the rebound effect could be minimised because the programme went along with information campaigns and social marketing mechanisms. However, the free-rider effect was high in the early years, because apart from saving energy [6], the main goal of the EPR was to channel back the energy tax to the tax payer (households). Regarding snap-back effects, the programme was effective for only a few years. After this period no supports were offered anymore but the increase in sales has also produced a decrease in the prices of A-labelled white goods. Their market shares remained at a significantly higher level than before.

Furthermore, the policy included innovative elements by using an intelligent policy package including a wide scale of information campaign, like national campaigns on television, national newspapers, advertisement in shops, actions targeting installers, and websites. Moreover the programme is in accordance with the EU energy labelling scheme and the Energy+ campaign that prepared the label sub-classes A+ and A++ for cold appliances. If a customer decides to buy an energy-efficient appliance, the energy label provides information, whether a funding is possible or not. The same mechanism was offered by the Energy+ campaign. The subsidies funded by an energy tax which was channelled back to the consumers through the utility is also an innovative element.

The EU energy label demonstrates the best available products on the market. The Energy+ campaign allowed to distinguish even higher energy efficiency within class A of the label. The energy premium scheme offered cash rebates for the purchase of these very energy-efficient household appliances. That is why the policy was close to a best available solution and fostered worldwide BAT.

To come back to the assessment scheme, a satisfying evaluation exists and the cost-effectiveness was calculated. In total, about 15% of the ecotax is used for the energy credit scheme. The amount of funds available to the citizens for 2000 and 2001 were 158 million €, of which 97% was actually spent. Another important measurable side effect were increases in VAT and taxes on profit and the avoided unemployment benefits. They were calculated for the case of washing machines: extra company profit tax: 1.9 million €/year and extra VAT: 6.6 million €/year [8].

Regarding cost-effectiveness, the energy savings were also high. In November 2001, almost two years after the start of the programme, one third of Dutch households had applied for the rebates. Around two thirds of these rebates concerned domestic appliances. The introduction of the premium scheme has led to an enormous growth of the supply of A-labelled and later A+ and A++-labelled appliances. The market share of A-labelled washing machines grew from 40 to 88% over the 1999-2001 period. This means the proportion of A-labelled appliances doubled and prices decreased (up to 25%). This increase is most likely due to the energy premium scheme and led to a situation where retailers very often advice their customers to buy an A-labelled appliance as the best on offer. An analysis of the Wuppertal Institute calculated that energy savings for household appliances of 300 GWh/year, plus 500 GWh/year in heating energy for buildings and 0.3 million tons of CO_2 were realised with the energy premium scheme programme until 2002 alone (including the market transformation effect and other side effects) [6].

According to this analysis and the positive results, the programme addressed selected market players and overcame existing barriers. It avoided lost opportunities and fostered lasting results. The policy had an innovative structure and promoted high and rapidly increasing energy efficiency standards, particularly for refrigerators and freezers (only A+ and A++ received rebates in 2003). The calculated cost-effectiveness and the achieved high energy savings confirm the successful implementation. Therefore the energy premium scheme can be named a good practice policy.

Summarising, the assessment scheme was successfully tested for a policy example– a financial incentive programme, which can be an essential element of the 'ideal' policy package –with the result that it is possible to identify good practice policies. The main barrier for the application of the bigEE assessment scheme is the availability of relevant data. For many policies, there is a lack of data due to the lack of attention to and funds for evaluation. Adequate information is often not available and national experts may be essential with appropriate background knowledge.

Good practice in policy packages to prove the results of the actor-centred analysis

In the previous chapter, the EnergiePremieRegeling was tested as a successful single instrument. Furthermore, the programme was also part of an effective policy package, which is a proof of our actor-centered analysis. The rebate scheme was developed in accordance with minimum energy performance standards, the European energy label, voluntary labelling schemes and information programmes. Particularly, the EU Energy label and the procurement programme Energy+ formed the basis for the EPR. They provided information, whether a consumer was entitled to a rebate when buying a specific model or not. The dynamic tightening of the requirements for award of a rebate (from A to only the equivalent of what became A+ and A++ later on), in turn, prepared the revision of the EU cold appliance label to include A+ and A++ subclasses, by enabling manufacturers to start mass production to meet the demand created by the EPR scheme. The package thus comes close to the 'ideal policy package' presented in figure 2.

Other examples for successful and coordinated policy packages for energy-efficient domestic appliances can be found, e.g., in Japan, Brazil and California. They, too, include innovative elements and demonstrate the successful interaction of different policies, like MEPS, labels, financial mechanisms, replacement programmes, procurement measures and information campaigns.

Conclusion

Energy efficiency is one of the most important issues in order to protect the climate and to stop the growing consumption of energy. For that reason, policy makers face the challenge to develop and implement appropriate instruments to increase energy efficiency of residential appliances. Such programmes are already in place in many countries. Especially minimum energy performance standards and labelling schemes were already implemented in industrialised but also developing countries. Different databases list these instruments and describe them briefly (see inter alia databases developed by CLASP and the International Energy Agency). It is also known that the interaction of several instruments guarantees the greatest success with push- and pull factors to influence all relevant actors and to tap all the available potential.

The refined approach, which was presented in this paper, illustrates how an actor-centred analysis enables developing an 'ideal' policy package, looking at the relevant market actors, their specific barriers and incentives, and concluding on implementation strategies which are derived from the earlier analysis. Based on this analysis, packages of policy instruments were identified, which are consistent with these implementation strategies. Since they address all relevant barriers, the package can be expected to transform the market towards high levels of energy efficiency.

This theoretical result was proofed by an empirical analysis, illustrated by a concrete example. To identify which policies and measures were successfully implemented and which factors were crucial to develop this policy, a multi-criteria assessment scheme was created and presented. The new scheme is justified by the fact that although several implemented policies are already in force, the effects of energy efficiency programmes are often poorly documented. Advantages and disadvantages are often unknown. That is why policy makers often rejected policy proposals because it seems too difficult to implement adequate measures. The empirical analysis tries to close this information gap by assessing the success and effectiveness of existing policies.

The newly created multi-criteria assessment scheme takes the analysis a step forward to rate policies and to define success factors. Criteria of the assessment scheme are primarily the energy savings and the cost-effectiveness of the policy but also the avoidance of negative side effects and the promotion of best available technologies. The new method rates policies and measures in more detail compared to already known schemes, which mainly focus on the effectiveness, the efficiency, the political feasibility and the innovation potential (see e.g. [5]). It goes beyond these approaches and considers the realised energy savings compared to the existing potentials, the cost-effectiveness and the design of the policy. The assessment scheme illustrates benefits of different policies and measures and thus aims to convince policy makers worldwide to transfer the policy from other countries in order to achieve similar results.

In the empirical part of this paper, the assessment scheme was exemplarily illustrated with the Energy Premium Scheme, which was implemented in the Netherlands in 2000. The review demonstrated the feasibility of the new method. According to the assessment scheme, the programme can be named a good practice policy and has therefore been successfully implemented. It is also a part of a policy package that comes close to the 'ideal package' and significantly accelerated energy efficiency in the market for cold appliances.

A precondition to use the assessment scheme is the availability of data. A comprehensive evaluation is essential to fill in the list of criteria. This is a precondition and therefore the biggest barrier of the scheme. Experts are necessary with a high level of knowledge about the policy-specific data and the design of the policy. A comparison of different measures is, therefore, still only feasible with considerable effort. However, the resulting comprehensive assessment and identification of what is really good practice will be worth the effort.

References

[1] Blumstein, C.; Goldstone, S.; Lutzenhiser, L.: *A Theory-Based Approach to Market Transformation*, Energy Policy28: 137-144 (2000)

[2] Ecofys Netherlands; Wuppertal Institute: *Theory Based Policy Evaluation to SMART Policy Design* – Summary report of the AID-EE project (Utrecht, 2007)

[3] International Energy Agency (IEA): *Evaluating Energy Efficiency Policy Measures & DSM Programmes* Volume I Evaluation Guidebook (Paris, 2005)

[4] IPCC: *Fourth assessment report of the Intergovernmental Panel on Climate Change* (Cambridge, New York, 2007)

[5] Schomerus, T.; Sanden, J.: *Rechtliche Konzepte für eine effizientere Energienutzung*, UBA Berichte 01/08 (Berlin, 2008)

[6] Thomas, S.: *Aktivitäten der Energiewirtschaft zur Förderung der Energieeffizienz auf der Nachfrageseite in liberalisierten Strom- und Gasmärkten europäischer Staaten: Kriteriengestützter Vergleich der politischen Rahmenbedingungen* (Wuppertal, 2006)

[7] World Energy Council; ADEME: *Energy Efficiency: A worldwide Review*. *Indicators, Policies, Evaluation* (London, 2004)

[8] Wuppertal Institute et al.: *Energy Efficiency programmes and Services in the Liberalised EU Energy Markets. Good Practice and Supporting Policy*. Background document produced by the project 'Bridging Energy Services to the Liberalised Markets (BEST) (2003)

The future of appliance efficiency policy: net zero energy using appliances.

Hans-Paul Siderius, Lars-Arvid Brischke

NL Agency, ifeu

Abstract

The electricity consumption of appliances in households is around 30% of total electricity consumption. In the last decades energy efficiency of appliances has improved, however total energy consumption of appliances is still increasing, particularly as a result of increasing penetration and functionality (number of functions, quality of provided services, size, capacity etc.) of appliances as well as frequency and duration of use. This begs the question whether current appliance efficiency policy is targeting the right goal.

Learning from the buildings sector, this paper introduces the idea of net zero energy using appliance as the (future) goal for appliance efficiency policy. Net zero energy using appliances are appliances that either have no connection to the mains or – on average – have zero energy consumption from the mains.

Goal of the paper is to stimulate the debate on the future of appliance efficiency policy by providing the idea of net zero energy using appliances. Therefore the paper will give a general overview on current appliance policy and the problems associated with these policies, provide a working definition of net zero energy using appliances and compare this with net zero buildings, give examples of net zero energy using appliances currently existing, provide principles of how to achieve net zero energy using appliances and give suggestions for policies.

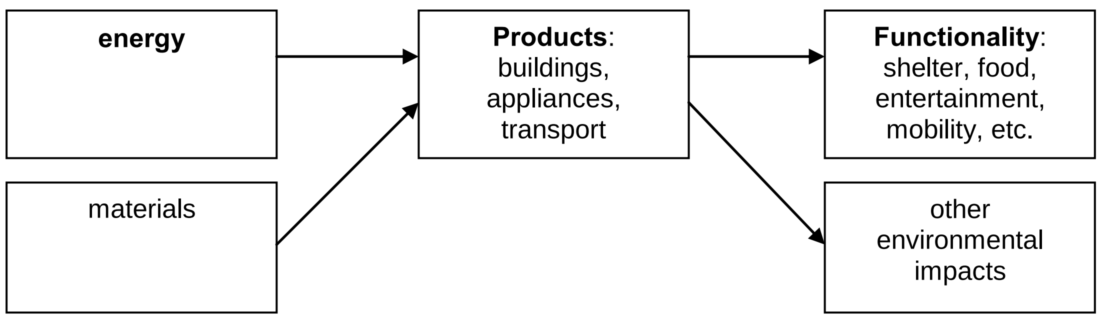
Keywords: appliance policy, energy efficiency, net zero energy consumption

Introduction

Climate change, security of supply and cost of energy force policy makers to reduce carbon intensive energy consumption and increase the share of renewables [1].

To achieve reductions in energy consumption we first must understand energy use. Energy is used in buildings, appliances and transport to provide certain functions or services: mobility, shelter, food, entertainment, clean clothes, etc. Besides, the use of buildings, appliances and transport results in use of materials, energy and other environmental impacts, e.g. noise, waste (figure 1).

Figure 1. Use of products



Most product policies to reduce energy consumption target at increasing energy efficiency. Energy efficiency of an appliance is the (amount of) functionality the product delivers per unit of energy or power, e.g. the viewable screen area per Watt for a television. Therefore, increasing energy efficiency can be a result of decreasing energy consumption of the appliance but also of increasing functionality (for the same or even increasing energy consumption), e.g. increasing the screen size of a television.

Consequently increasing the energy efficiency of a product does not automatically result in a lower energy consumption of the product.

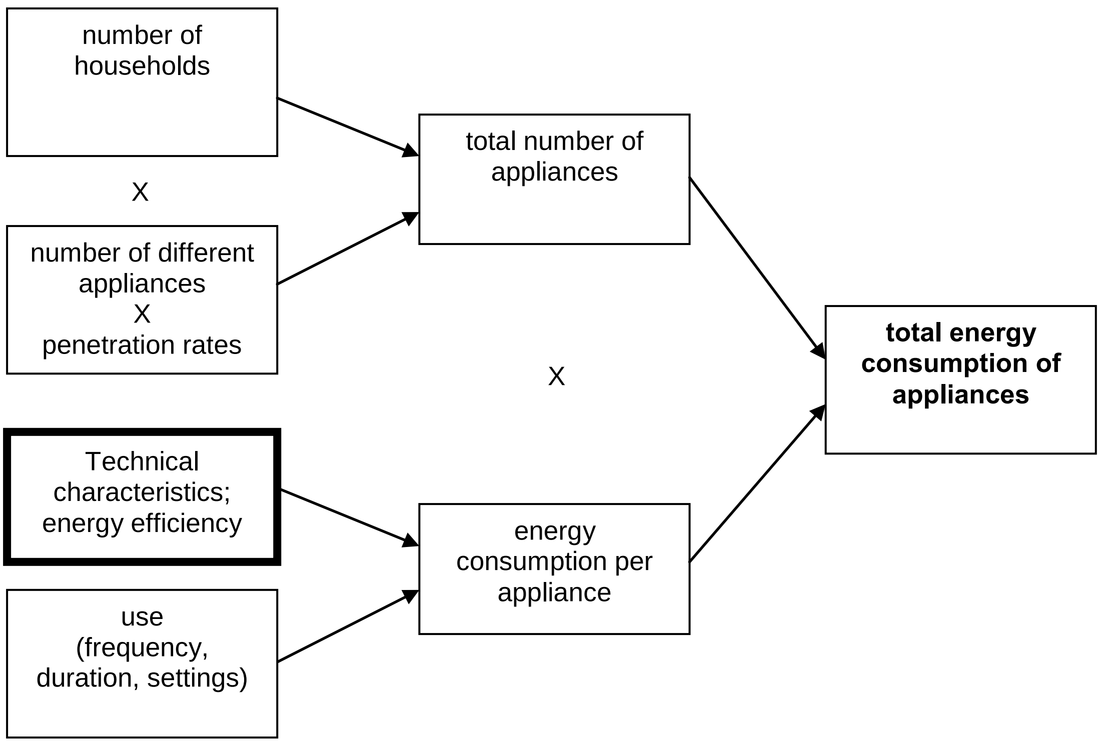
In this paper we call for the development of net zero energy using appliances to make a contribution towards a carbon neutral society. The energy consumption of electrical appliances in households is about 30 % of total electricity consumption [2][1]. The further increase of electricity consumption due to (over)compensation of increasing energy efficiency by increasing functionality and use of the products (rebound effect) could be avoided by a comprehensive use of net zero energy using appliances. So net zero energy using appliances would make a significant contribution to reduce total electricity consumption, assuming that the energy needed for production and disposal does not increase more than the energy savings. This vision has been inspired by net zero energy buildings and zero carbon vehicles exist already. This paper will be restricted to electrical household or consumer appliances, because their lower power consumption per product[2] makes them a good candidate to start with.

This paper is organized as follows. First we will describe shortly the current situation and trends regarding energy consumption of household appliances and policies to reduce energy consumption of these appliances. Second, we will elaborate on the vision of net zero energy using household appliances, provide a definition and give examples of net zero appliances currently existing. Finally, we provide principles of how to achieve net zero energy using appliances and we will indicate how the development of net zero energy using appliances can be stimulated.

Current situation in appliance policy and trends

Household appliances consume 30 % of total electricity generated and their consumption is increasing [7]. Household appliances provide a large range of services for the end-user: clean dishes, dry clothes, entertainment, communication with others, food storage and preservation, etc.

Figure 2. Determinants of appliance energy consumption



In general the energy consumption of appliances is determined by (see also figure 2):

---

[1] A rough estimate from more recent IEA statistics (2006, 2008) confirms this figure.

[2] Compare e.g. with (large) electric motors used in industry.

- The ***number*** of appliances: the number of appliances per household (number of different appliances times penetration rates) times the number of households;

- The ***use*** of appliances: frequency of use (e.g. using the dishwasher 6 times a week), settings (e.g. 60 ^{o}C cotton cycle for washing) and duration (e.g. the television is on (on average) 4,5 hours per day);

- The ***technical characteristics*** of appliances: the capacity of the appliance, the efficiency of the power supply or the motor, etc.

Current appliance policies focus on part of the technical characteristics: the energy efficiency of the appliance. Two main type of policies can be distinguished whether they involve the end-user or not:

- Minimum efficiency standards do not involve the end-user[3]; manufacturers will make their products comply with the requirements. In most cases minimum efficiency standards are set by governments and are mandatory, but e.g. the EU Ecodesign directive [3] provides the possibility for industry to propose a voluntary agreement as alternative for legislation.

- Information on product energy consumption or energy efficiency, whether to be provided mandatory, e.g. the EU energy label, or voluntary, e.g. the Energy Star label, requires (also) the involvement of the buyer/end-user to have effect.

Few policies have been designed to influence the use of appliances, most notably washing at lower temperature (60 or 40 ^{o}C instead of 90 ^{o}C), washing with a full load or switching appliances off when not in use. The policies used in this case are mainly information campaigns[4] which we will not look at in this paper. Also ideas have been brought forward regarding the controls and operation of appliances, influencing behavior by technical means e.g. the IEEE Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments. (Std 1621-2004, June 8, 2005).

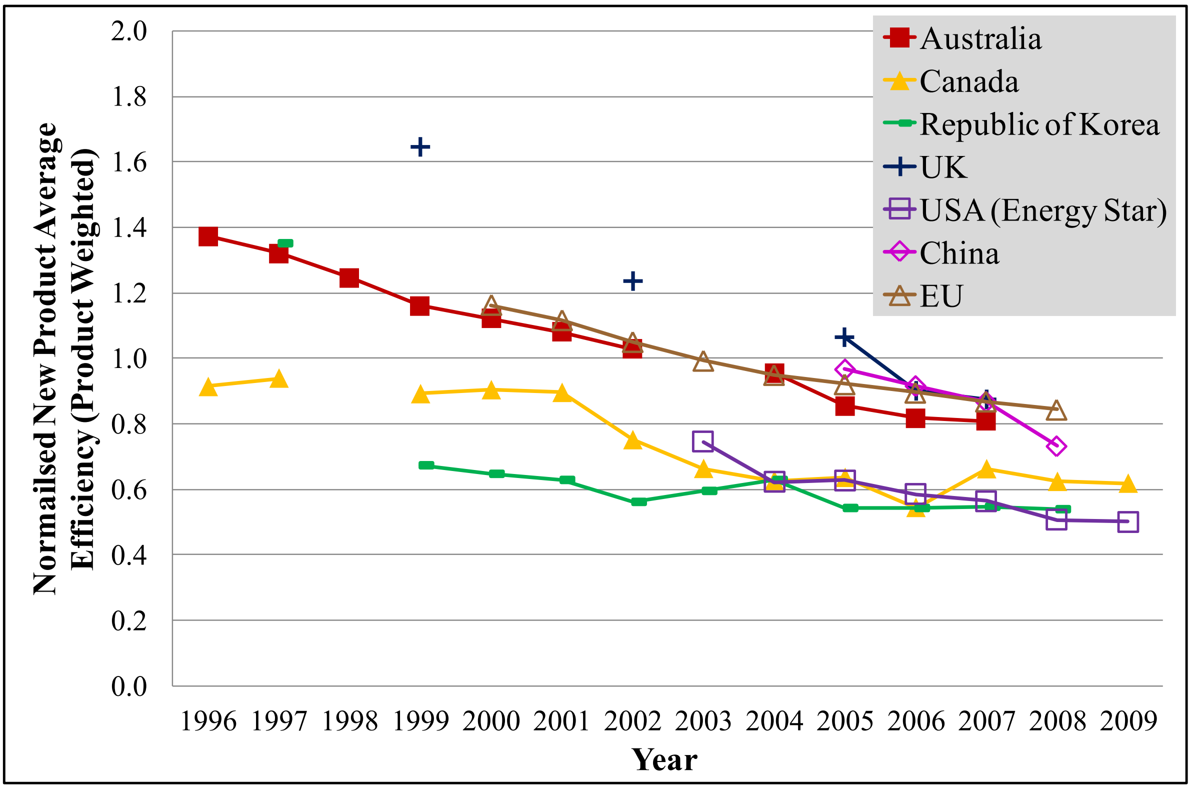
As a result of appliance policies and autonomous developments the energy efficiency of many (regulated) appliances has improved, see the example in figure 3, for other examples see www.mappingandbenchmarking.iea-4e.org.

---

[3] Some aspects in Ecodesign regulations, which are generally seen as EU minimum efficiency standards, are usage related, e.g. the automatic power-down of televisions after 4 hours without interaction and/or channel change [10].

[4] For example the *Initiative EnergieEffizienz* in Germany - a nationwide information and motivation campaign and a platform for action targeting the efficient use of electricity in all consumer sectors. It provides the end consumer, professionals and opinion makers with information and advice on the potential for energy efficiency that exists where ever electricity is used. In particular it shows how the individual can use electricity efficiently in the home. The campaign is supported by the German Federal Ministry of Economics and Technology (BMWi) and numerous partners from the business world [11].

Figure 3. Development of energy efficiency of refrigerator-freezers (Source: [4])



However, as indicated above, increasing energy efficiency does not automatically result in energy savings. Moreover, as figure 2 shows, the technical characteristics of a product are only one aspect influencing the energy consumption of appliances, so (mainly) targeting the technical characteristics will leave other factors free to increase energy consumption. For example the annual electricity consumption related to televisions was estimated to be 60 TWh in 2007 in the EU and it is predicted that it will increase to 132 TWh in 2020, if no specific measures are taken to limit it [10]. The regulations for televisions (Ecodesign and energy label) aim to increase the market penetration of energy efficient televisions leading to estimated electricity savings of 28 TWh by 2020, compared to the situation without taking any measures. This means that if the regulations will be effective, the expected *increase* will be dampened and the electricity consumption of televisions in the EU will "only" increase to 104 TWh in 2020, which is still an increase of more than 70 % compared to the consumption in 2007.

In the rest of this section we elaborate on these problems.

First, the relation between energy efficiency, energy consumption and functionality. Energy efficiency of appliances can be defined as the delivered functionality of the appliance per unit of energy used[5]. In most cases the delivered functionality is expressed in the capacity of the appliance, e.g. screen area for televisions and computer monitors, storage volume for cold appliances, number of place settings for dish washers.

An example of this "trade-off" between capacity and energy consumption is provided by the 4E[6] Mapping & Benchmarking data on washing machines for the EU [5]: the energy consumption of the average standard wash decreased from 2000 till 2005 by 0,035 kWh/year, whereas the average capacity increased by 0,077 kg/year in that period. From 2006 till 2009 however, the energy consumption of the average standard wash stayed the same, whereas the average capacity increased by 0,16 kg/year. As a result the improvement in efficiency (kWh/kg) decreased from on average 0,012 kWh/kg/year in the first period (2000-2005) to 0,006 kWh/kg/year in the second period

[5] For household appliances this is in most cases kWh.

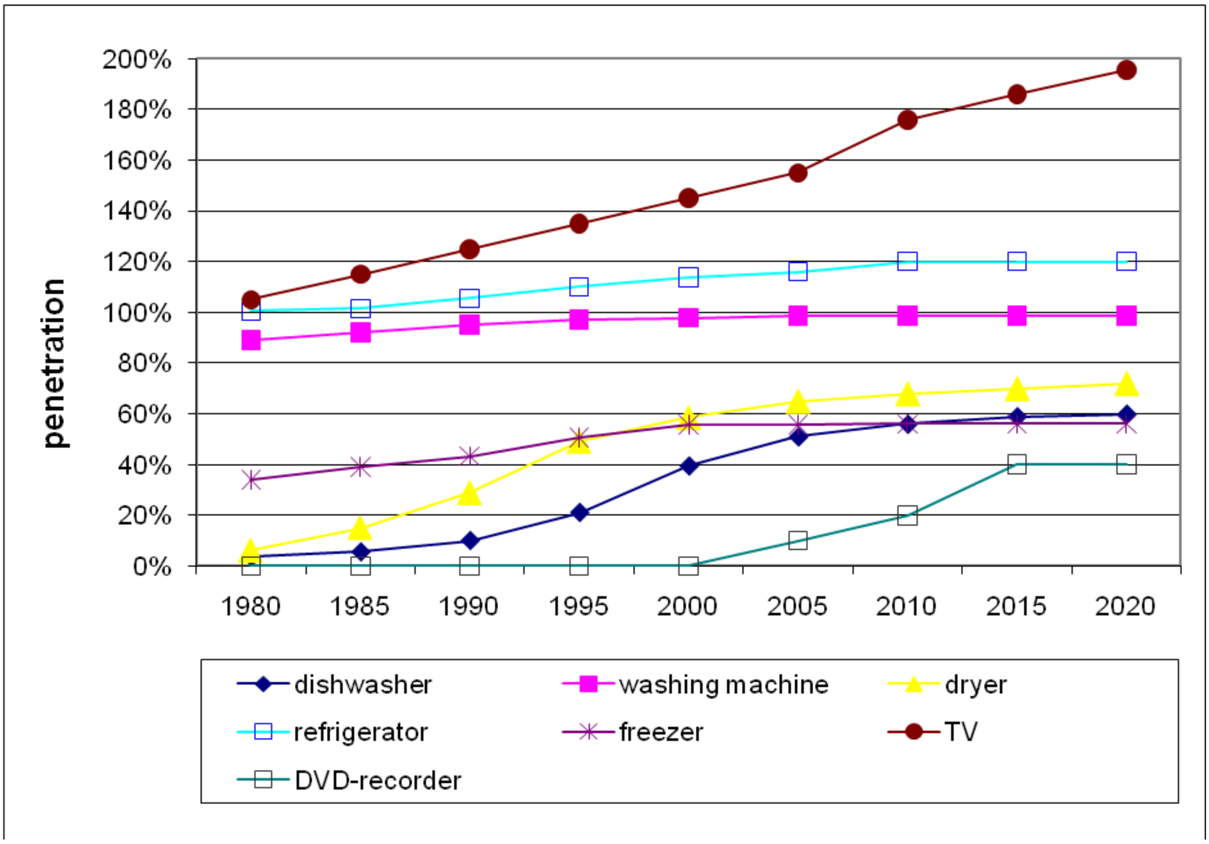
[6] Efficient Electrical End-use Equipment; an IEA implementing agreement, see www.iea-4e.org.

(2006-2009). This means that the increase in capacity in the period 2006-2009 resulted in a slower increase in efficiency.

The conclusion is that improvements in energy efficiency are not only used to decrease energy consumption but also to increase functionality, including capacity. Given the decreasing household size in the EU, it can be questioned whether this increased capacity is really needed, but it is difficult for policy makers to answer this question.

Second, looking at the other determinants of energy consumption, not only the penetration but also the number of (energy using) appliances has increased (see figure 4).

Figure 4. Penetration rates for appliances in the Netherlands (Source: [6]; 2010, 2015 and 2020 figures based on estimates)



Another trend is the increasing "use" of appliances. For example the daily viewing time of TV-programs per person (analyzed in 30 regions worldwide) increased from 205 minutes in 1997 to 229 minutes in 2007 [13]. This includes appliances being in a network standby mode: the ecodesign preparatory study on networked standby losses estimates that the energy consumption due to network standby in the EU will increase from 52 TWh/year in 2010 to over 90 TWh/year in 2020 [20]. Al large part of this increase is due to increased network availability. There is little doubt that these trends, certainly on worldwide scale, will continue (see e.g. [7]).

Third, the increasing number of products and product variants pose a problem for appliance efficiency policies. Since appliance policies are mainly implemented per product, an increasing number of new or revised products require an increasing number of minimum efficiency standards or labels, including new or revised test procedures. Because the government capacity of issuing regulations is limited, the chances are that products policies are not implemented for all new products or that policy revision will not keep up with product developments.

Finally, these other determinants, i.e. use, penetration rate, number of appliances and number of households, are far more difficult to tackle by (appliance) policies than energy efficiency. In general influencing the number of households is not seen as a suitable energy policy. As indicated above some policies target the use of appliances (on a voluntary level) and also product buying advice schemes raise the issue of buying product with the right capacity[7] (not larger than your needs), but policies discouraging buying an appliance are in general not practiced by governments. Although there are good reasons for this hesitation because such a policy would directly effect the freedom of consumer choice, this means that there is a limit to the contribution of current *product* policy regarding decreasing total energy consumption of appliances.

Concluding, the increasing energy consumption of appliances poses problems regarding achieving the policy goals of climate change, security of supply and the affordability of energy. Although energy efficiency certainly can be improved further, it is unlikely that an 80 % reduction in CO_2 emissions can be achieved with appliance efficiency policy alone when these trends continue. The main reason is that appliance efficiency policy currently is targeting a limited part of a growing problem. The solution can be sought outside the scope of appliance policy, e.g. by capping total electricity consumption (per household) and/or requiring that all (household) electricity is generated in a sustainable way ("green" electricity). However in this paper we will stick to appliance policy and show another way.

Buildings and transport have already shown the way forward: net zero energy buildings[8] and carbon neutral transport options exist and are being developed further. If the energy consumption of a product would be (near) zero then the total energy consumption of that product would be (near) zero regardless the use or the number of products[9]. Net zero energy using appliances are part of an overall strategy to achieve a sustainable energy society, i.e. all energy used in all sectors is produced in a sustainable way. A sustainable energy society is also a carbon neutral society where security of supply is no longer a problem and energy is still affordable. In the next section we look how these sectors can inspire the appliance sector.

Net zero energy using appliances as policy goal

Definition of net zero energy using appliances

Net zero energy using appliances are appliances that either have no connection to the mains[10] at all or – on average – have a zero electricity consumption from the mains. The aim of net zero energy using appliances is to minimize the electricity demand of private households which is to be covered by electricity suppliers, but it is not electricity autarky of households. Appliances consuming on average net zero power from the mains are in line with the visionary idea of smart grids to cover and optimize power production and consumption from the inside of the cellular, dezentralized "prosumers" (power consumers which are power producers as well) outwards to the mains connecting all of them.

The concept of net zero *energy* using appliances is a more rigorous concept than net zero carbon appliances. Net zero carbon means that both the energy consumed by the appliance is produced in a sustainable way (e.g. "green" electricity) and the CO_2 emissions resulting from the production of the appliance are compensated for. However, the appliance itself still uses electricity from the mains. Even when all electricity would be produced in a sustainable way, i.e. by renewable energy sources, net zero energy using appliances would still bring additional the following benefits:

1. Economic benefit for the consumer in situations where the energy produced by the appliance is less expensive then the energy generated by renewable sources and distributed by the mains.

---

[7] For example the German campaign *Initiative EnergieEffizienz* recommends for white goods capacities per person in order to tune the capacity to the specific household size [12].

[8] Note that the concept of net zero energy buildings is restricted to the functions heating, cooling and ventilation (and in some cases lighting) – the so called "wired" or fixed installations in combination with the building shell and orientation, and therefore does not include the other (household) appliances.

[9] However, other environmental aspects, e.g. use of (scarce) material, may become a limiting factor to the number of products.

[10] In Europe for most household appliances: 230 V, 50 Hz. Rechargeable batteries, that are charged by the mains, are also considered as connection to the mains. Furthermore, a PV system with a 12 V DC home power grid would of course also benefit from net zero energy using appliances.

2. Independency: The consumers' technical and economic dependency (e.g. concerning energy prices) on energy suppliers could be minimized and the technical reliability could be increased.
3. Ecologic benefit: The generation and distribution of electricity by renewable sources distant from the end user cause consumption of resources and environmental impact which could be minimized by net zero energy using appliances as well.

An example of an established zero energy using device is the solar calculator and it has proven a million fold over the last decades. Because a solar calculator works without battery this results a considerable conservation of resources whereas the power savings are rather negligible.

Sensors are an example where there is a direct benefit of producing the needed electricity at the product. Most sensors require a few mW to function and only μW when in rest. Supplying these powers by the mains results in inefficiencies; even if the most efficient power supply for such a sensor would only use 0,01 W in standby and has a 50 % efficiency this would result in power consumption that is about 11 times larger than when directly produced by the sensor[11].

Net zero energy using appliances can be seen as the ultimate smart grid situation where each electricity consuming device is also an electricity producing device. The main difference is that the concept of net zero energy using appliances targets the appliance manufacturers, whereas the concept of net zero carbon appliances mainly targets the electricity producers.

Examples of net zero energy using appliances

Net zero energy using appliances already exist; certainly most of them are portable micro or small devices yet. They benefit from self energy supply in particular by more flexibility for portability. Well known examples are beside the mentioned solar calculator and wireless sensors, hand powered radios and flashlights or automatic watches using the mechanical energy of body movements. Examples for new zero energy using products are solar battery chargers, or a milk frother supplied with energy exclusively by an internal accumulator, which is recharged by a solar generator integrated within the appliance (see figure 5).

Figure 5. Examples of net zero energy using products: mobile battery charger [14], solar milk frother "SoLait" [15], solar roller shutters [16].

Source: www.bahnshop.de Source: www.solarc.de

Wireless sensors are micro applications of the piezoelectric effect. An example how to apply this effect on macro level is the pilot project at Tokyo station, where piezoelectric panels generate electricity from vibrations of more than 80.000 passengers per day [17].

---

[11] Assuming the sensor uses 10 mW for 1 s every 10 s and has a rest consumption of 10 μW, this would result in a yearly energy consumption of 8,8 Wh, compared to $0{,}02W \times 876h + 0{,}01W \times 7884h = 96$ Wh when produced by the power supply.

The challenge is to develop zero energy consumption for appliances like cold appliances, washing machines, computers or televisions. An advantage of large appliances is that the energy generator needs not be as lightweight and small as generators for mobile applications. Appliances developed for solar home systems deliver first experience how appliances have to be designed to become zero energy using appliances, e.g. refrigerators and freezers: highly-efficient cooling, very low energy requirement, minimal thermal losses, adjustable interior temperature, 12 V or 24 V DC etc. [18].

Even if appliances like refrigerators or washing machines already showed a remarkable increase of energy efficiency over the last decades, it is conceivable that further substantial improvements of energy efficiency could be reached by changing currently applied physical or technical principles. Assuming a successful R&D it could be possible that refrigerators and freezers using cooling effects of changing magnetic fields which work without compressor will be available or washing machines working without water and save the laundry dryer as well [19].

Guidelines for developing net-zero energy using appliances

The principle of a net zero energy using appliance can be expressed in the following "equation" where the equal sign means 'on average over time':

appliance energy consumption = appliance energy production
↑
storage
exchange with grid

This equation provides the following guidelines for developing net zero energy using appliances:

- Decrease energy consumption to a minimum (tailor the functionalities of the appliance to users' demand):
    - eliminate all unnecessary energy consumption, e.g. functions never demanded or used,
    - use most efficient available components,
    - and match the functions provided by the appliance and the required functionality at that moment, e.g. by implementation of an effective power management so that only those parts of the appliance are powered that are necessary.
- Increase energy production of or at the appliance by use of
    - physical principles merged in the concept of energy harvesting and energy scavenging devices which use ambient energy on a low level of density [9]: piezoelectric effect which occurs e.g. due to vibrations, tearing and wearing of materials etc, electromagnetic / inductive energy harvesting and the thermoelectric effect,
    - ambient heat,
    - solar input,
    - hand power etc.
- Very efficient energy storage or exchange with the grid: energy generated at the appliance might not be used at the same moment and needed at times when generation is less than the demand.

If we try to apply these guidelines for a cold appliance as an example, the following suggestions arise. Decreasing energy consumption would mean decreasing energy loss from the appliance as far as possible. In general two situations can be distinguished: energy losses when the doors are closed and energy losses due to door openings (exchange of air, putting in products that are warmer than the interior temperature). Energy losses with doors closed can be reduces by improving insulation.

However, energy losses due to door openings are given, so e.g. door openings (and closings) should generate more energy than is lost.

Also network standby could also be an area for net zero energy: if only a low network availability is required, meaning that the reactivation time of the appliance can be 10 s or more, the power needed to maintain the network connection is relatively low and could be provided by the appliance itself.

In general the concept of net zero energy appliances forces developers to think beyond energy efficiency. What is the functionality that really needs to be provided by the appliance? What can be provided without energy use and what is – given the energy production capacity of the appliance – the available energy "budget"? The concept will also set a natural limit to the capacity of an appliance: capacity can not be stretched endlessly, but the size has to be carefully chosen related to the energy budget.

Battery powered products provide a good benchmark to start with and a source of inspiration because to keep the product functioning for as long as possible without recharging (or replacing the batteries) components have to be very efficient and power management must be applied rigorously. Compare e.g. the power consumption needed by a netbook (around 7 W including the display [21]) and a desktop computer (around 100 W without monitor [22])[12].

Consequences and policies to support net zero energy using appliances

Since appliances count for around 30 % of total residential electricity consumption net zero energy appliances would contribute to a large extent in meeting climate change targets and increasing security of supply. In combination with net zero energy buildings the comprehensive use of zero energy appliances would lead to a significant change in the structure of final energy demand: The rate of total final energy consumption of the residential sector would dramatically decrease to a negligible level compared with the sectors industry and transport.

But are net zero energy appliances also affordable? Because the energy costs are zero, the purchase price of the appliance can be higher than the current purchase price and still achieve lower overall costs. The following simple example shows that for a refrigerator the purchase price could more than triple: a refrigerator with a life time of 12 years, a purchase price of € 275 and energy consumption of 200 kWh/year will at 0,25 €/kWh have total costs of € 875. What this certainly would mean is a redistribution of revenues: more money for the appliance manufacturers and less for the electricity companies.

Such an increase in "up front" costs for net zero energy using appliances probably requires the development of new, innovative models of financing (e.g. deferred payment) or even of new approaches for the ownership in appliances (e.g. leasing, micro contracting). Hence home services which today are provided by appliances could be in the future services sold instead of appliances.

Policies to support the development of net-zero energy using appliances

Product policy and research policy can be used to support the development of net zero energy using appliances. First of all the concept of net zero energy using appliances should be an inspiring vision and research policy programmes, e.g. 7th Framework Programme, can be used to stimulate (fundamental) research in this field.

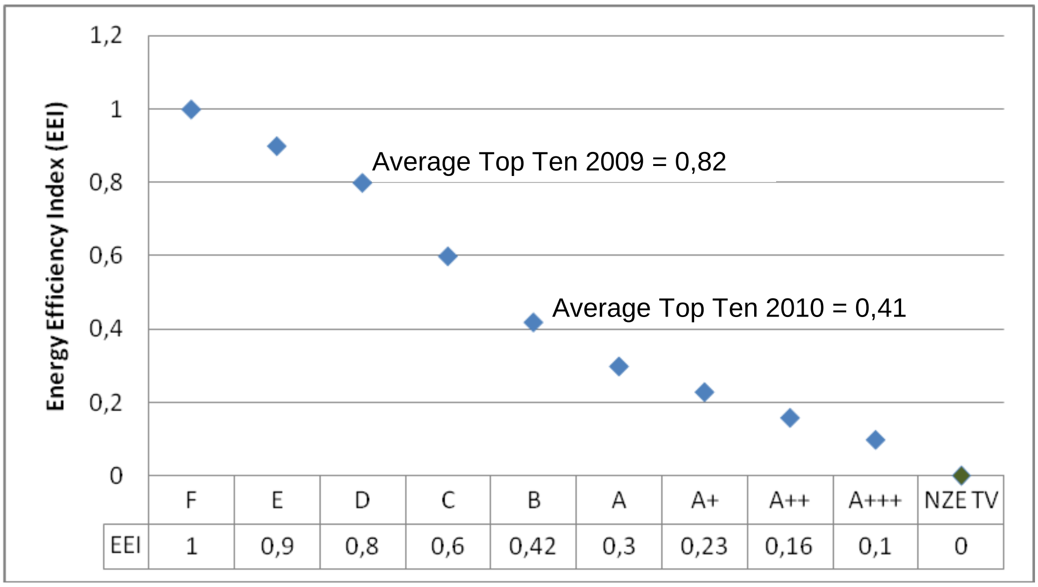
Second the concept of net zero using appliances could be used as a long term goal for product efficiency policy. This could be expressed by reserving from 2020 the A energy class of the EU energy label for appliances that are net zero energy appliances. Figure 6 shows that the energy classes of the EU energy label for televisions [8] already move in that direction. Furthermore, figure 6 shows that in 1 year the most efficient televisions (according to the Top Ten project; www.topten.info) have become twice as efficient. Currently the most efficient televisions have an EEI of 0,25.

---

[12] One could argue that the functionality of a netbook and a desktop computer is different, but e.g. both are used for word processing, e-mail, internet etc.

Regarding minimum efficiency standards, expressing these standards in terms of absolute consumption (power or energy) instead of efficiency would also stimulate manufacturers to look for low energy solutions. Otherwise (larger) products not meeting the energy consumption target could no longer be placed on the market. The expectation is that these solutions will then also be applied to smaller products in order to achieve the net zero energy A class.

Figure 6. EU energy label classes for televisions



Conclusions

This paper showed that the increasing energy consumption of appliances poses problems regarding achieving the policy goals of climate change, secrurity of supply and the affordability of energy. Furthermore, we argued that net zero energy using appliances could be part of an overall strategy to achieve a sustainable energy society where all enery used in all sectors is produced in a sustainable way.

Examples of net zero energy using appliances already exist and we presented general guidelines to develop these appliances. For larger appliances, e.g. refrigerators and televisions to become net zero energy using appliances, it needs stimulus from research and development programmes and support by other policy measures, e.g. the EU energy label.

References

[1] European Commission. (2010). Energy 2020; A strategy for competitive, sustainable and secure energy. Brussels: European Commission; COM(2010) 639 final.

[2] IEA. (2003). Cool Appliances; Policies Strategies for Energy Efficient Homes. Paris, IEA.

[3] European Union. (2009). Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast). *Official Journal of the European Union L285* , 10-35. Can be downloaded at: http://europa.eu.int/eur-lex/.

[4] 4E Mapping & Benchmarking Annex. (2010). Benchmarking of Domestic Cold Appliances. http://mappingandbenchmarking.iea-4e.org/, 23 August 2010.

[5] 4E Mapping & Benchmarking Annex. (2010a) Mapping Document EU Washing Machines. http://mappingandbenchmarking.iea-4e.org/, 10 September 2010.

[6] Elburg, M. van, Elektrische apparatuur in Nederlandse huishoudens (Electrical Appliances in Dutch Households). Van Holsteijn en Kemna, Delft, 2008.

[7] Ellis, M. Gadgets and Gigawatts; Policies for Energy Efficient Electronics. IEA, Paris, 2009.

[8] European Commission, Commission delegated regulation No 1062/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and the Council with regard to energy labeling of televisions, OJ L 314 p.64-80, 30.11.2010.

[9] Priya, S., Inman, D. J. (Ed.): Energy Harvesting Technologies. New York, Springer, 2009.

[10] European Commission, Commission regulation (EC) No 642/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for televisions, OJ L 191 p. 42-52, 23.7.2009.

[11] Deutsche Energie-Agentur (dena): http://www.dena.de/en/topics/electricity/, visited 6 January 2011.

[12] Deutsche Energie-Agentur (dena): Energiespartipps für Haushaltsgeräte. Berlin, 2009; http://www.dena.de/de/themen/thema-strom/publikationen/publikation/haushaltsgeraete/, visited 6 January 2011.

[13] GfK Retail and Technology: Unterhaltungselektronik. Marktentwicklung und Trends. Dena Expert Workshop on Energy Efficiency of Consumer Electronics, 19 November 2008; http://www.initiative-energieeffizienz.de/veranstaltungen/experten-workshop-tv-geraete.html, visited 6 January 2011.

[14] http://www.bahn.de/bahnshop1435/shopxml/design/index.shtml; visited 6 January 2011.

[15] http://www.solarc.de/cms/pages/en/products.php; visited 6 January 2011.

[16] http://www.roma.de/htm/start/frameset.php?modus=10|0|0|1|x|x|rolladen_|3; visited 6 January 2011.

[17] http://www.physorg.com/news148116916.html; visited 6 January 2011.

[18] http://www.phocos.com/products; visited 6 January 2011.

[19] WWF: Modell Deutschland. Klimaschutz bis 2050 – Vom Ziel her denken. Ökoinstitut, Prognos: Berlin 2009.

[20] Nissen, Nils F. and Lutz Stobbe. EuP Preperatory Studies Lot 26: Networked Standby Losses, Draft Final Report: Task 5 Definition of Base Cases, Fraunhofer Institute for Reliability and Microintegration IZM, Berlin, 15 December 2010.

[21] Müssig, Florian. Das Zweite Atom-Zeitalter. c't 2010 Heft 8, p. 124-133.

[22] Benz, Benjamin. Arbeitstiere. c't 2010 Heft 15, p. 128-135.

Latest Changes to UK Compliance Approach and Powers

Iain Notman

Department for Environment, Food and Rural Affairs, United Kingdom

Abstract

Energy efficiency legislation needs an effective enforcement regime to: safeguard the intended environmental and economic benefits; protect compliant businesses from unfair competition; and ensure consumers benefit from the anticipated financial savings.

In 2009 and 2010, the UK Government reviewed the effectiveness of its existing market surveillance and enforcement regime for legislation on mandatory minimum energy performance standards and energy labelling requirements for products. This found that increasing compliance rates could bring significant net financial benefits to the UK, as well as reducing greenhouse gas emissions. As a result of the review, responsibility for market surveillance and enforcement was transferred from local government level to a single market surveillance authority (MSA) with responsibility for market surveillance and enforcement across the whole of the UK. In addition, to enable a more flexible and proportionate approach, a suite of civil sanctions were added to the existing criminal penalties for breaches of the legislation on minimum energy performance standards. Powers were also introduced to reclaim the costs of testing products found to be non-compliant. Similar changes to energy labelling legislation are currently being considered.

The Challenge

The challenge facing Governments when implementing energy efficiency legislation is how to deliver an effective enforcement regime that helps to ensure:

- the legislation delivers the intended environmental and economic benefits;
- businesses that have saved costs by not complying with the legislation do not gain an unfair advantage over businesses that are fully compliant;
- consumers purchasing energy efficient products benefit from the anticipated financial savings through lower energy bills;

and at same time:

- allows, or even encourages, economic progress and only intervenes when there is a clear case for protection.

This paper outlines how the UK Government is updating its enforcement regime to meet this challenge more effectively.

Energy Efficiency Legislation

The UK Government has a range of policies to promote energy efficient products. These include: the provision of advice; financial incentives; voluntary labelling schemes; and mandatory minimum standards and labelling requirements. In order to protect the functioning of the European Union's (EU) Internal Market, these minimum standards and labelling requirements for products are set at a European level.

Minimum Standards and Labelling

Minimum standards are set under the Ecodesign Directive. This is the legal framework within which the European Commission brings forward implementing measures on specific products or product groups in order to improve their environmental performance. These measures aim to drive up standards by removing the least efficient products from the market. The original Ecodesign Directive was agreed in 2005 [1]. Existing EU energy efficiency requirements became implementing measures under this Directive.

Energy Labelling Directive [2] was adopted in September 1992. This provides the legal framework for directives for specific products. Labelling informs consumers of the relative energy efficiency of products and so enables them to choose more energy efficient products. It also incentivises manufacturers to develop products which are more energy efficient than the minimum standards require.

The EU Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan, published in July 2008, included commitments to expand the scope of Ecodesign and Energy Labelling Directives to cover products which did not necessarily use energy themselves but had a significant impact on energy use and could therefore contribute to saving energy [3]. (Potentially products might include windows, insulation material or bathroom devices, shower heads or taps). A recast Ecodesign Directive [4] was subsequently adopted in October 2009 and a recast Energy Labelling Directive [5] in May 2010. Member States are required to transpose these Directives by November 2010 and June 2011 respectively.

Enforcement

Under the principle of subsidiarity, enforcement regimes are set at the national level. Nevertheless, both Directives require Member States to take measures to ensure that the Directives are complied with and to set penalties that are “effective, proportionate and dissuasive”. Further requirements on enforcement regimes are set in the EU Regulation 765/08 on Accreditation and Market Surveillance (RAMS) [6]. This was adopted in July 2008 and came into force on 1 January 2010. It requires Member States to make sure that only goods that comply with European product legislation are allowed onto the European internal market. These requirements include having competent organisations in place with the ability to deal with non-compliance using credible systems of powers and penalties.

Review of Enforcement

In 2009 the UK Government decided that it was time to review the effectiveness of its enforcement regime for these Directives, now that the legislation had been in place for several years. The recast Ecodesign Energy and Labelling Directives would require changes to UK legislation. It was also necessary ensure that UK legislation was consistent with RAMS. This was therefore a convenient opportunity to implement any changes arising from the review.

Levels of Product Compliance

There is a shortage of hard data on levels of non-compliance. Nevertheless, estimates based on European wide research carried out by ANEC (the European Association for the Co-ordination of Consumer Representation in Standardisation) suggested that 15% of energy using products placed on the market were non-compliant with energy labelling and minimum standards legislation [7]. (Provisional results from the ATLETE project, published in April 2011, show similar levels of non-compliance. ATLETE found that 16% of appliances tested failed to comply with the energy efficiency class declaration and two related key parameters: energy consumption and storage volume. Just 47% complied with all five test parameters [8].) These high levels of non-compliance were borne out by the UK Government’s own research.

Between 2005 and 2009, the UK Government carried out testing exercises regularly on a range of product groups and published reports of the findings [9]. Products tested included: washing machines, washer driers, ovens, oil and gas fired boilers, domestic wet appliances, ballasts, air conditioners, and lamps. Appliances were purchased anonymously and tested by accredited test laboratories to assess whether they met the claims on their energy labels. In each case, only one appliance was tested and not the four required for a full test of compliance. The final set of reports was published in November 2009. These showed that at least 15% (and for some products as high as 25% or more) of the appliances tested did not appear to perform to the standard claimed.

Costs of Non-Compliance

As part of its review, the UK Government produced an impact assessment on the potential costs and benefits of different enforcement regimes [10]. In view of the shortage of hard data, this used estimates and assumptions based on expert opinion. The aim was to assess the order of magnitude of the costs and benefits of different options so as to help inform decision making.

The table below is taken from the impact assessment and summarises the estimated degree of product non-compliance, based on expert opinion. It assumes that 10% of products are legally non-compliant and that 40% of products are below their stated level but within the legal tolerance levels[1]. Legal tolerance levels were included in the calculation because it was expected that manufacturers would react to a stricter compliance and enforcement regime by taking steps to reduce the risk that their products fail the compliance tests. This would have the effect of reducing the amount by which products deviated from the standard within these legal tolerance levels. The overall non-compliance rate was calculated to be 6.2%. This was considered to be a very conservative estimate, as indicated by the test results referred to above.

This non-compliance rate was taken to be analogous to the proportion of the projected energy savings that would not be achieved due to non-compliance. It could then be used to calculate the proportion of the overall benefits (eg reduced energy and CO_2e[2] savings) and costs (eg non-traded CO_2e emissions from the heat replacement effect) from reduced energy consumption that would not be achieved due to non-compliance.

Table 1 – Estimated % Level of Non-Compliance with the Energy Labelling Framework Directive[3]

	% of products in each 'non-compliance category'	**% they are deviating from required standard**	**% currently lost from non-compliance**
'Non-compliant' but within tolerance	40	10	4
Deviating by one energy label class	8	20	1.6
Deviating by more than one energy label class	2	30	0.6
Total			6.2

Again based on expert opinion, the impact assessment estimated that 14% of the total costs to manufactures and consumers of achieving full compliance would be incurred in achieving the remaining 6.2% reduction in energy consumption. This estimate was derived under the following assumptions:

- the 40% of products deviating only within the legal tolerance avoid 20% of the cost;
- the 8% of products deviating by one energy label class avoid 50% of the cost; and
- the 2% of products deviating by more than one energy label class avoid 100% of the cost.

[1] Tolerances are built into EU Regulations which set mandatory minimum standards. These are error allowances mainly to take into consideration possible laboratory and measurement variations. (These vary from 5% to 15% depending on the product). A product that does not strictly meet the minimum standard but falls within the tolerance level is still legally compliant.

[2] Carbon dioxide equivalent.

[3] Non-compliance with minimum standards, set under the Ecodesign Directive, was also expected to be significant. However it was not added to the rate of non-compliance due to the risk of double-counting. In practice, a product which does not meet the minimum energy label class has a high risk of not meeting the ecodesign standards, thus infringing both Directives.

Therefore, (40% x 0.2) + (8% x 0.5) + (2% x 1) = 14% of costs to manufacturers, (which are passed on to consumers) are avoided due to non-compliance.

Based on initial estimates of the total projected net benefits from the Ecodesign and Energy Labelling Directives, for 21 product categories (for the period 2010-2020), the net present value of these measures was estimated as:

- Present value total benefits: £11.3bn
- Present value total costs: £2.7bn

It was also estimated that 80% of the total costs of measures under the Ecodesign and Energy Labelling Directives resulted from costs incurred by manufacturers and passed on to consumers. The remaining 20% was due to costs associated with greater household heating (because of the heat replacement effect when more efficient appliances were used).

The overall costs of non-compliance were estimated as follows:

- Applying a 6.2% rate of non-compliance to the overall projected benefits from improving compliance (such as reduced energy bills and CO_2e savings) gives a cost of non-compliance of £700m.
- Applying a 6.2% rate of non-compliance to the costs imposed on society due to increased household heating requirements (because of the heat replacement effect) gives a benefit of non-compliance of £34m.
- Applying a 14% rate of non-compliance to costs not incurred by the manufacturer or imposed on consumers gives a benefit of non-compliance of £302m.

This resulted in total present value costs of non-compliance of £700m, and total present value benefits of non-compliance of £336m. Therefore, the net present value foregone (between the period 2010-2020) due to non-compliance was £364m (€416m)[4].

CO_2e Savings Not Achieved

Another effect of non-compliance is that some of the projected CO_2e savings are not achieved. At the time the impact assessment was drafted, the UK had carried out detailed analysis of projected carbon emissions savings from the 11 ecodesign implementing measures that had been or were due to be voted upon by mid-2009. Based on these, the impact assessment estimated that the total projected net CO_2e savings figures for these 11 measures in 2020 (ie traded sector savings minus non-traded sector increases) were about 7.2Mt. Applying the estimated 6.2% rate of non-compliance could therefore result in missing out on saving over 0.4Mt of CO_2e a year by 2020.

Context for Review: General Review of Regulatory Principles

The review of the effectiveness of the enforcement regime for the Ecodesign and Energy Labelling Directives was informed by two important wider reviews of regulation in the UK.

Hampton Review

In March 2004, the UK Government asked Philip Hampton to lead a review into ways to reduce the administrative burden of regulation on businesses, while maintaining or improving regulatory outcomes. The Hampton Review consulted key stakeholders through a series of meetings, seminars, focus groups, business case studies and in-depth surveys. It also considered relevant reports and studies. The final report was published and its recommendations accepted by the Government in March 2005 [11]. The following findings and recommendations were of particular relevance to the review of the enforcement regime for the Ecodesign Energy and Labelling Directives.

---

[4] The figures in Euros quoted in this paper are calculated using the exchange rate as of 16 May 2011.

The few businesses that persistently break regulations should be identified quickly and face proportionate and meaningful sanctions. Businesses and regulators have an interest in proper sanctions against illegal activity in order to prevent businesses operating outside the law from gaining a competitive advantage. Existing regulatory penalties did not take the economic value of a breach into consideration and it was quite often in a business's interest to pay the fine rather than comply. The Review encountered several examples of fines that did not reflect economic benefit gained from illegal operation. For instance:

- a man was paid almost £60k (€69k) to dump drums of toxic waste illegally. The waste cost the local authority £167k (€191k) to incinerate, yet the offender was fined only half the sum he had been paid; and

- a waste company failed to register for a waste disposal licence for two years, saving £250k (€286k). It was fined £25k (€29k).

Regulators should provide authoritative, accessible advice easily and cheaply. This could increase the probability of compliance, and hence regulatory outcomes. More broadly, better advice eases businesses' concerns about the requirements of regulation, and helps them to comply. The Review's work and other surveys suggested a large unmet need for advice. For instance, a DTI report in 2002 said that small businesses were not clear what regulators expected of them [12]. Similarly, an academic study in 2003 suggested that 62% of small food business proprietors did not understand which food safety regulations were relevant to them, while 42% did not understand hazard analysis – a fundamental part of food safety requirements [13].

Regulators should be of the right size and scope. Smaller regulators could create small centres of expertise. However, they did not benefit from the sharing of experience and expertise that larger organisations could more readily embrace. It was difficult for Government to allocate resources to areas of importance if funding for regulation was divided among many different bodies. The problem of fragmentation existed at both national and local authority level. Many local authorities had small regulatory services departments, and so could not give their staff an opportunity to specialise. For example, the average number of staff in Trading Standards Offices (TSOs) was 51 staff in counties, 17 staff in London and metropolitan boroughs, and 14 staff in unitary authorities.

Macrory Review

In September 2005, the UK Government asked Professor Richard Macrory to lead a review to ensure that the system of regulatory sanctions was consistent with the recommendations of the Hampton Review. The Macrory Review carried out extensive formal and informal consultation, as well as considering relevant reports and studies. The final report was published in November 2006 [14]. The following findings and recommendations were of particular relevance to the review of the enforcement regime for the Ecodesign Energy and Labelling Directives.

The Review found that there was heavy reliance on criminal sanctions as a formal response to regulatory non-compliance. However, it concluded that, although criminal sanctions were an effective tool in some circumstances, relying too heavily on them could be ineffective for several reasons. For instance, as noted by the Hampton Review, the financial sanctions imposed in some criminal cases were not considered to be a sufficient deterrent or punishment. On the other hand, where there had been no intent or wilfulness in the regulatory non-compliance, a criminal prosecution might be a disproportionate response. The Review therefore recommended a suite of sanctions that could be added to the regulators' enforcement toolbox. These would broaden the flexibility available to regulators, the judiciary and business to better meet regulatory objectives, improve compliance and ensure a level playing-field for all.

Criminal Sanctions: The Review concluded that the use of criminal prosecutions would remain appropriate for serious breaches of regulations. Ultimately, a regulator was obliged to uphold the public interest and maintain a credible enforcement and sanctioning regime. It should therefore have the flexibility to apply a sanction for punitive reasons, even though a lesser sanction could be applied. This could include punishment and the public stigma associated with a criminal conviction. This might be necessary for so-called 'repeat offenders' who had been given previous opportunities – alongside advice and guidance – to comply, but had deliberately and intentionally failed to do so. Similarly, a punitive sanction might be appropriate for a single contravention with very serious external consequences.

Monetary Administrative Penalties: Having considered the academic literature, international experience and the responses to the consultation process, the Review concluded that monetary administrative penalties were an effective way of ensuring regulatory compliance, whilst reserving criminal prosecutions for the most serious of cases. These would be fines that were applied directly by a regulator. The recipient would have a right to appeal through an administrative appeals mechanism.

Monetary administrative penalties could provide an intermediate step between the formal, costly and stigmatising action of criminal prosecution and the more informal means of advice and persuasion to get firms back into compliance. They could be used in circumstances that required a formal sanction but not necessarily a criminal prosecution.

Statutory Notices: The Review recommended the strengthening and extending of the existing system of statutory notices in cases of regulatory non-compliance. It cited a body of research that had raised some of the limitations of relying on fines alone to change business behaviour. The limitations highlighted by the review included that financial penalties alone might not incentivise businesses to take appropriate measures to address procedures within the business that gave rise to the offence. Instead of taking the necessary steps to build long-term compliance, corporate managers might decide to treat fines as recurrent business losses.

Statutory notices would be intended to address this problem. These notices require the recipient to do or refrain from a particular behaviour. They specify the steps a business must take in order to be compliant and the timescale for these changes. Failure to carry out the actions laid out in the notice might also be an offence.

Enforceable Undertakings: The Review recommended the introduction of enforceable undertakings. These would be legally binding agreements between the regulator and business, under which the business agreed to carry out specific activities to rectify its non-compliance. They could include commitments to future regulatory outcomes, including steps to ensure that specific types of incident did not re-occur. They would represent a valuable alternative to traditional regulatory enforcement action because they could address the needs of several parties involved in, or affected by, the wrongdoing as well as correcting and preventing breaches and their underlying causes.

Enforceable undertakings in the form recommended by the Review were not a sanction that was in use in the UK at the time. However, the Review concluded that experience in other countries demonstrated their effectiveness. For instance, a report for the Australian Competition and Consumer Commission – cited by the Australian Law Reform Commission in its review of regulatory penalty schemes – concluded that Enforceable Undertakings provide a quicker and more cost-effective mechanism for resolution of regulatory non-compliance than court proceedings [15].

Previous Enforcement Regime

The enforcement regime for the Ecodesign Energy and Labelling Directives prior to 2009 exhibited many of the problems highlighted by the Hampton Review.

Market Surveillance

Market surveillance and enforcement was carried out at local government level by TSOs. The role of TSOs was to implement the main laws relating to: weights and measures; the quality and fitness for sale of merchandise; food standards; animal welfare; fair trading; and consumer protection.

The Hampton Review reported that there were 203 TSOs in England, Scotland and Wales. Resources were therefore spread too thinly to effectively carry out the very expensive and technical testing required by energy efficiency legislation. For example, using data from the 2009 testing exercise referred to above, the impact assessment estimated the costs of testing a single appliance to be on average £3k. For most products, EU regulations require a further three appliances to be tested to prove non-compliance. This gives a total cost for testing of £12k (€14k). Similarly, the broad remit of TSOs made it difficult for staff to develop the necessary specialist experience.

Penalties

The only sanctions available under the existing legislation were criminal. These showed the weaknesses highlighted by the Hampton and Macrory Reviews. Cases could be tried at a magistrates' court or the Crown Court. Most cases were likely to be tried at the magistrates' courts, where the maximum fine for non-compliance is £5k (€6k) (in part due the costs for both parties of going to the Crown Court). This level of fine was considered an insufficient monetary deterrent for companies with a high turnover. On the other hand, a criminal conviction in a magistrates' court was considered excessive for a minor offence.

Consultation on Options

The Government held a public consultation from June to September 2009 on options to improve market surveillance and enforcement of the Directives. The consultation sought views on which authority or authorities should be responsible for enforcement. It also set out proposals for a civil sanctions regime and a system for sharing the costs of testing.

The consultation document set out the following options for comment [16].

- Option 1: TSOs retain responsibility for market surveillance and enforcement.
- Option 2: A central Government Body takes on this responsibility.
- Option 3: TSOs continues to enforce the requirements for domestic products, but a different body enforces the requirements for-non domestic products.

Under all the options, TSOs would retain responsibility for enforcing the requirements on retailers to display energy labels at the point of sale because this fitted well with their other regular inspections in retail premises. The consultation document identified Option 2 as the Government's preferred option. The impact assessment referred to above was published as an Annex to the consultation document to help inform consultation responses.

Net Benefit of Increased Compliance

The impact assessment considered the potential costs and benefits for each of the above options. It also considered three product testing regimes for each of the three types of institutional arrangement. These were for every product group to be subjected to either detailed testing or testing of samples: every five years; every two years; or every year. These were intended as indicative for evaluation purposes of scenarios for testing regimes rather than an exhaustive list of potential options.

Option 2, with the two year testing regime, was found to be the most cost effective enforcement regime. Option 2 produced the greatest increase in compliance rates of the three institutional arrangements. The testing regime, under which all product groups were subjected to full or partial testing every year, produced a greater increase in compliance rates than the regime where they were tested every two years. However, this increase in compliance rates was not sufficient to offset its higher cost.

The impact assessment estimated that even with a fully effective enforcement regime, there would remain an absolute deviation in each category of non-compliance (including within legal tolerances) of 5%. This was because there would always be a minority of manufacturers who were prepared to take the risk and introduce non-compliant products onto the market. There would also always be instances of errors in product labelling or mistakes made during the manufacturing process which could lead to products being non-compliant. The table below is taken from the impact assessment and shows the resulting impact on the level of non-compliance. The impact assessment therefore concluded that the best possible outcome would be for the losses of projected energy savings to be reduced from 6.2% to 2.5%. This implies a maximum potential improvement of 3.7%.

Table 2 – Estimated % Level of Non-Compliance with the Energy Labelling Framework Directive with 5% Deviation

	% of products in each	Absolute deviation	% deviating from

	'non-compliance category'	(%) from claimed energy savings with thorough compliance	claimed savings could be reduced to...
'Non-compliant' but within tolerance	40	5	2
Deviating by one energy-label class	8	5	0.4
Deviating by more than one energy label class	2	5	0.1
Total			2.5

The impact assessment estimated that Option 2 combined with Regime 2 would reduce non-compliance by 3% to 3.2%. This would produce net benefits of £164m (€187m) over the period 2010-2020.

Appointment of NMO

Responses to the consultation were received from a range of organisations including NGOs, trade associations, manufacturers, professional associations and energy companies. The summary of responses was published in September 2009 [17]. These showed strong support for Option 2, a central Government Body taking on responsibility for market surveillance and enforcement.

The Government agency, the National Measurement Office (NMO), was therefore appointed in November 2009 as the market surveillance authority (MSA) with responsibility for market surveillance and enforcement of the Ecodesign Energy and Labelling Directives across the whole of the UK. As proposed in the consultation, TSOs retained responsibility for enforcing the requirements on retailers to display energy labels at the point of sale.

The NMO's new role fitted well with its existing responsibilities, which included ensuring that trade measurements used by both industry and consumers were fair, accurate and legal. NMO also acted as the MSA under Restriction of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations (RoHS) and Batteries and Accumulators (Placing on the Market) Regulations. It was chosen because it had demonstrated the collaborative approach to market surveillance and enforcement recommended by the Hampton Review. It was dedicated to working closely with industry, including manufacturers, retailers and importers, to raise awareness of and improve understanding of obligations and assist companies in their compliance.

The NMO was tasked with carrying out a programme of risk based compliance testing. This would focus on bringing products into compliance, rather than moving straight to issuing penalties or prosecution.

Penalties

The June 2009 consultation also sought views on the principle of introducing a range of civil sanctions as proposed by the Macrory Review and outlined above. In addition, it set out proposals for sharing the costs of testing products for compliance. It proposed that, should an appliance fail the first test, then the manufacturer or legal importer would be required to pay for the costs of the tests required by legislation on further samples to demonstrate compliance.

Responses to the consultation gave broad agreement to the proposed range of penalties. This included clear support for retaining criminal sanctions for the most serious offences. The majority of responses also supported the principle of cost sharing. However, views differed on how costs should be split between Government and business.

Further Consultation on Penalties

Following the consultation, the proposals for civil sanctions and cost sharing were worked up in more detail. A further public consultation on these detailed proposals was held from March to June 2010

[18]. This was accompanied by impact assessments of the costs and benefits of the proposals [19], [20].

The consultation document proposed the introduction of the following civil sanctions, in line with the recommendations of the Macrory Review. It also proposed the retention of criminal sanctions for the most serious offences.

Compliance Notice: A written notice issued by the MSA, which requires the manufacturer/retailer/legal importer to take actions to comply with the law, or return to compliance within a specified period.

Stop Notice: A written notice which requires a manufacturer/retailer/legal importer to cease activity that is causing harm or presents a serious risk of causing serious harm.

Enforcement Undertakings: A voluntary agreement by a business to undertake specific actions that would make amends for non compliance and its effects within a specified timeframe. Examples of enforcement undertakings could include for the manufacturer: to offer customers a replacement model or reimburse them for their higher than expected electricity costs; and agree to undertake specific action in order to ensure compliance in the future.

Variable Monetary Penalty: A proportionate monetary penalty imposed by the MSA. The size of the penalty would depend on issues such as: the severity of the breach; the number of non-compliant appliances placed on the market; and the resulting CO_2 emissions.

Appeals

The consultation also proposed a robust system to deal with appeals against civil sanctions. It was proposed that appeals be heard by the General Regulatory Chamber of the First-tier Tribunal. This tribunal is part of the administrative justice system of the UK. It is empowered to deal with a wide range of issues and to ensure cases are dealt with in the interest of justice while minimising parties' costs. The composition of a tribunal is a matter for the Senior President of Tribunals to decide. It may include non-legal members with suitable expertise or experience in the issues of the appeal, in addition to Tribunal Judiciary.

Cost Sharing

In view of comments received in response to the earlier consultation, the Government revised its proposals for sharing the costs of testing. It proposed that the MSA be given the power to require manufacturers to pay for the costs of testing, only if it were proven that their product did not comply with the ecodesign legislation, in accordance with the "polluter pays" principle. This would reduce the burden on the taxpayer of dealing with non-compliance, and incentivise greater compliance in the future.

The impact assessment on cost sharing used the same estimates of compliance rates and testing costs as the earlier impact assessment referred to above. Using these, it estimated that an indicative programme of 200 tests would cost around £600k (€686k). Under these proposals, the MSA could potentially reclaim up to £162k (€185k) of these costs.

Introduction of New Powers

A large majority of the responses to the consultation supported the proposals on civil sanctions and cost sharing. A summary of the responses was published in October 2010 [21]. This explained that the Government would add civil sanctions and cost sharing, as set out in the consultation document, to the enforcement regime for the Ecodesign Directive. The necessary powers would be included in the forthcoming Ecodesign for Energy Related Products Regulations 2010 [22]. These Regulations transposed the recast Ecodesign Directive referred to above. They subsequently became law in November 2010.

The response to the consultation also explained that the recast Energy Labelling Framework Directive referred to above had been agreed after the launch of the consultation. The Government would introduce regulations in 2011 to transpose the requirements of this Directive into UK law. As part of this process, the Government would carefully consider the potential inclusion of civil sanctions and cost sharing in these regulations.

Assessing Effectiveness of New Regime

The Government also made a formal commitment to draw up a framework to monitor the use of the new sanctioning powers. It would create a forum to review results from the monitoring framework with stakeholders before a formal review. This forum would contribute to an assessment of whether the new powers were being used consistently and in line with the published enforcement policy and guidance. A formal review of how the new sanctioning powers were being implemented would be carried out two years after their introduction.

International Collaboration

In addition to changes to the domestic enforcement regime, the UK Government also prioritised action at the global level to ensure effective compliance. International collaboration avoids the wasted cost of duplicated activity and at the same ensures there are no safe havens for suppliers of non-compliant products. The UK Government is therefore working in collaboration with partners internationally to gain and share experience of how to improve compliance with energy efficiency regulations.

Administrative Cooperative Group (ADCO)

The UK chaired European network of enforcement authorities (Administrative Cooperative Group – ADCO – for market surveillance of Ecodesign) in its first year. Through the ADCO, the UK Government is promoting information sharing, increased product testing and harmonisation of approaches to enforcement across Europe. For example, the UK is leading the development, in partnership with several Member States, of a joint project to develop systems and best practice for effective monitoring, verification and enforcement of the Ecodesign Directive across the Single Market.

International Energy Agency

The UK is also participating in efforts of the International Energy Agency (IEA) to raise the profile of product compliance worldwide. In 2008, we supported a workshop on improving compliance [25]. This identified a number of challenges to effective compliance and also opportunities to address these. The UK hosted a follow-up international conference on compliance in September 2010 [24]. This was organised jointly by the International Energy Agency (IEA) and the Collaborative Labelling and Appliance Standards Program (CLASP). Experts examined procedures used by individual programmes to monitor, verify and enforce (MV&E) energy efficiency regulations. The conference agreed the need for further collaboration. This is now being taken forward by the IEA.

The UK inputted to the drafting of a practitioners' guidebook by CLASP [25]. This was launched at the conference and provides practical information on compliance based on the experiences of existing programmes in various countries. The UK also inputted to the IEA policy pathway on monitoring verification and enforcement [26]. This was considered at the conference and released by the IEA in October 2010.

Strengthening Test Standards and Procedures

Test standards are an essential component of any compliance and enforcement system. These are the processes by which the energy efficiency of a particular product is determined. To be effective, they need to be clear, unambiguous, repeatable and, as far as possible, represent real life consumption of a product when in use. Within the EU, the European Commission issues mandates to EU standardisation bodies to develop test standards. However, it retains the final decision, once a test standard has been developed, as to whether the standard should be adopted for EU legislation. The UK Government is working to strengthen its oversight of and, when necessary, participation in the development of test standards both within Europe (via the British Standardisation Institute and CENELC Technical Committees) and internationally, via the International Electro-technical Commission (IEC).

Conclusions

The UK Government's review of the effectiveness of its existing market surveillance and enforcement regime for the Ecodesign Directive and the Energy Labelling Directive found that non-compliance was causing the UK to miss out on significant potential net financial and carbon savings. As a result, a more effective regime could bring significant net benefits to the UK. It is also found strong support from business and other stakeholders for such changes.

The review concluded that two important changes were required. The first was that the MSA needed to have in depth knowledge and expertise, together the capacity to focus sufficient resources on the often costly process of testing and enforcement. The Government agency, the NMO, was therefore appointed in November 2009 as the MSA with responsibility for market surveillance and enforcement of the Ecodesign and Energy Labelling Directives across the whole of the UK. Previously, this responsibility had rested at local government level with TSOs.

The second change was that the MSA needed a range of enforcement tools that would enable them respond in a flexible and proportionate way to non-compliance. New civil sanctions for breaches of the ecodesign legislation were therefore introduced into UK law in November 2010, as were powers to reclaim the costs of testing products found to be non-compliant. Similar changes to energy labelling legislation are currently being considered.

In a global economy, where the same product is frequently sold in several countries, international collaboration is also important to ensure effective compliance. The UK is therefore working with partners to achieve this both within the EU and globally.

References

[1] European Commission. Directive 2005/32/EC establishing a framework for the setting of ecodesign requirements for energy-using products. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32005L0032:EN:PDF

[2] European Commission. Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31992L0075:en:PDF

[3] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan, 2008. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0397:FIN:EN:PDF

[4] European Commission. European Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:en:PDF

[5] European Commission. Directive 2010/30/EU on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0001:0012:EN:PDF

[6] European Commission. Regulation (EC) No 765/2008 of the European Parliament and of the Council of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products and repealing Regulation (EEC) No 339/93. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:218:0030:0047:en:PDF

[7] ANEC. A review of the range of activity throughout Member States related to compliance with the EU Energy Label regulations in those countries, December 2007

[8] ATLETE. Press release date 12 April 2011. Can be downloaded at: http://www.atlete.eu/doc/EN%20FINAL%20-%20PRESS%20RELEASE%20-%20ATLETE%20FINAL%20CONFERENCE.pdf

[9] The reports published by Defra between 2005 and 2009 are available at: http://www.mtprog.com/cms/compliance

[10] Defra. Impact Assessment of the compliance and enforcement regime of the Energy-Using Products (EuP) & Energy Labelling Directives, 2009. Can be downloaded at: http://webarchive.nationalarchives.gov.uk/20100505154859/http://www.defra.gov.uk/corporate/consult/eup-labelling/index.htm

[11] Philip Hampton. Reducing administrative burdens: effective inspection and enforcement, March 2005. Can be downloaded at: http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/bud_bud05_hampton.htm

[12] DTI. Cross cutting review of government services for small businesses, October 2002. Available from UK Department for Business, Innovation and Skills (BIS)

[13] Charlotte Yapp, and Robyn Fairman. Factors affecting food safety compliance within small and medium-sized enterprises: Implications for regulatory and enforcement strategies, 2004.

[14] Professor Richard B. Macrory. Regulatory Justice: Making Sanctions Effective, November 2006. Can be downloaded at: http://www.bis.gov.uk/policies/better-regulation/reviewing-regulation/improving-compliance-among-businesses

[15] Australian Law Reform Commission. Principled Regulation: Federal, Civil and Administrative Penalties in Australia, 2002

[16] Defra. Consultation on the Implementation of the Market Surveillance and Enforcement Requirements of the Eco-design of Energy Using Products and Energy Labelling Framework Directives, June 2009. Can be downloaded at: http://webarchive.nationalarchives.gov.uk/20100505154859/http://www.defra.gov.uk/corporate/consult/eup-labelling/index.htm

[17] Defra. Summary of responses to the Consultation on the Implementation of the Market Surveillance and Enforcement Requirements of the Eco-design of Energy Using Products and Energy Labelling Framework Directives held 11 June 2009 – 4 September 2009. Can be downloaded at: http://webarchive.nationalarchives.gov.uk/20100505154859/http://www.defra.gov.uk/corporate/consult/eup-labelling/index.htm

[18] Defra. Consultation on the introduction of Civil Sanctions and Cost Sharing for the Energy Using Products and Energy Labelling Regulations, March 2010. Can be downloaded at: http://www.defra.gov.uk/corporate/consult/eup-labelling2010/index.htm

[19] Defra. Impact Assessment of the Proposed Penalty Regime for the Energy Using Products and Energy Labelling Regulations, March 2010. Can be downloaded at: http://www.defra.gov.uk/corporate/consult/eup-labelling2010/index.htm

[20] Defra. Impact Assessment of Cost Sharing Options available to the Market Surveillance Authority under the Energy Using Products and Energy Labelling Regulations, March 2010. Can be downloaded at: http://www.defra.gov.uk/corporate/consult/eup-labelling2010/index.htm

[21] Defra. Summary of responses and Government response to the consultation on the introduction of civil sanctions and cost sharing for the Energy Using Products and Energy Labelling Regulations held from 23rd March – 15th June 2010, October 2010. Can be downloaded at: http://www.defra.gov.uk/corporate/consult/eup-labelling2010/index.htm

[22] The Stationery Office. The Ecodesign for Energy-Related Products Regulations 2010, 2010. Can be downloaded at: http://www.legislation.gov.uk/uksi/2010/2617/contents/made

[23] The record of the workshop and presentations are available at: http://www.iea.org/work/workshopdetail.asp?WS_ID=349

[24] The record of the conference and presentations are available at: http://www.iea-4e.org/events-and-meetings/compliance-conference

[25] CLASP. Compliance Counts: A Practitioner's Guidebook on Best Practice Monitoring, Verification, and Enforcement for Appliance Standards & Labeling, 2010. Can be downloaded at: http://www.clasponline.org/files/Compliance%20Counts_%20A%20Practitioner_s_Guidebook%20on%20Best%20Practice%20Monitoring,%20Verification,%20and%20Enforcement%20for%20Appliance%20Standards%20&%20Labeling.pdf

[26] IEA. Monitoring, Verification & Enforcement: Improving compliance within equipment energy efficiency programmes. Can be downloaded at: http://www.iea.org/papers/pathways/monitoring.pdf

Recommended measures for electricity savings in the Netherlands

Edith Molenbroek, Kornelis Blok (Ecofys)

Wouter Wienk (AgentschapNL)

Abstract

At the end of 2009 energy advisory groups to the Ministry of Economic Affairs in the Netherlands decided that more attention should be paid to efficient use of electricity: in the household sector, services sector as well as in industry.

Electricity consumption in these sectors keeps rising, whereas electricity savings could and should contribute more to overall energy savings targets.

Therefore, a working group on electricity savings was put in place by AgentschapNL, agency for the Ministry of Economic Affairs. In the first half of 2010 workshops were held, followed by further analysis. It was concluded that there are many possibilities for stimulation of efficient electricity use. A general recommendation for electricity savings to policy makers is to consider electricity efficiency explicitly in the preparation, development and implementation of policy measures. A general observation is that in all sectors, but on a government level as well, increased insight into electricity savings is a key to success. Altogether sixteen recommendations have been formulated, five of which for the household sector.

In the paper, we will discuss facts and figures on electricity consumption in the Netherlands, followed by a discussion on the recommendations for the household sector. The proposed recommendations can lead to more than 10% in savings in electricity consumption for households annually.

The measures formulated do not involve huge government spending. They do require active participation and commitment from companies, institutions as well as the government.

Introduction

Electricity consumption in the Netherlands keeps increasing and is responsible for almost a quarter of the country's greenhouse gas emissions. The pace of electricity savings is lagging behind, even compared to the average pace of energy saving. On the other hand, the potential for electricity savings is huge. A few factors that make savings difficult are

- The incentive given by the European system of emissions trading is minimal: less than 1 cent/kWh. This is insufficient for most sectors to achieve acceleration in the pace of savings.
- This latter is mainly to do with the fact that the consumption of electricity is relatively insensitive to the price of electricity.
- Electricity saving often requires a specific approach, because electricity consumption is usually very diffuse: it is spread across many different units (lights, computers, engines, etc.), each with millions of users.

All of this makes electricity savings very complex – there are no simple solutions.

The approach of the Dutch working group on energy savings was as follows:

Three workshops were held, one of which for the household sector. A group of 10 – 15 people was invited to the workshop, with representatives from government, NGO's, industry and the retail branch. Beforehand, an introduction document was sent with facts and figures on consumption and relevant existing policies. At the workshop, an introductory presentation was held, followed by a brainstorm and a first selection of ideas that had resulted from the brainstorm. This selection of ideas was then discussed and further worked out to specific recommendations by prof. Blok and the other members of the core working group. After one feedback round to the workshop participants the recommendations and the report were finalized.

When commencing this work, it was realized by the core working group that government policy is largely limited by the following preconditions:

- Pricing policy has only a limited effect due to low price elasticity.
- It is largely the responsibility of the European Union, in the context of the Ecodesign directive, to establish efficiency norms for electrical equipment. As a result of this directive, it is not possible for a Member State to impose additional requirements.
- Government budgets will be limited in the future, leaving little room for stimulation via subsidies and tax incentives[1].

Therefore, the recommendations were aimed at businesses and branch organisations, environmental and consumer organizations as well as authorities, to help mobilise them into saving electricity.

Dutch households fact and figures

The household sector comprises 23% of the total electricity demand in the NL. Electricity consumption in the NL has increased on average by 1.5% per year from 2000 to 2008. Estimated efficiency increase in the same period was 1.1% per year[i]. In figure 1 it is shown how the electricity consumption is distributed among the different categories, as modeled by VHK in 2008[ii].

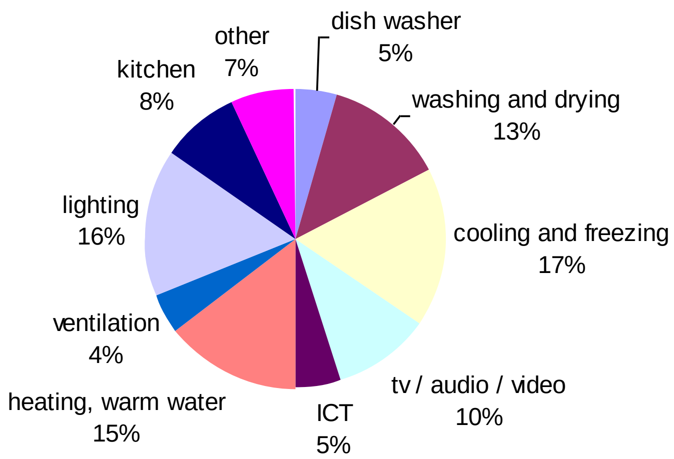


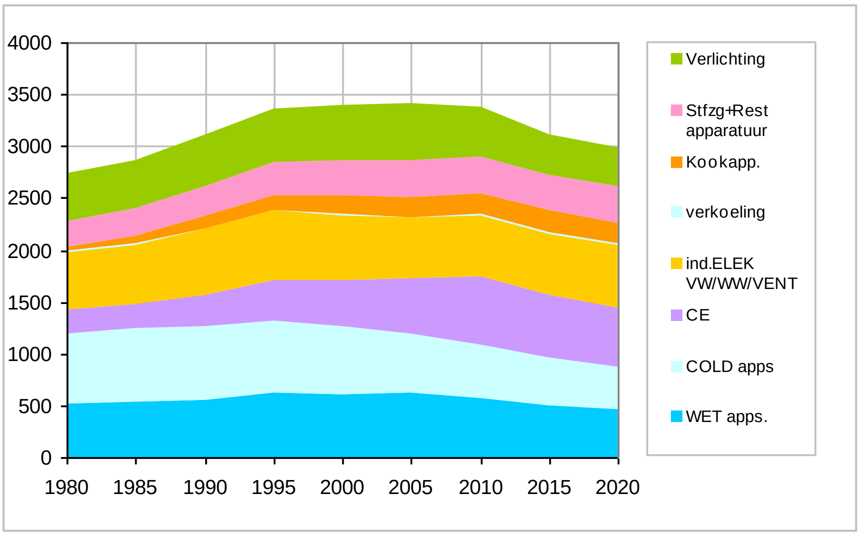
Figure 1 Distribution of household electricity consumption over different consumption categories[ii].

An average household, comprising of 2.3 persons, consumed 3420 kWh of electricity in 2008.

---

[1] In fact, a study for the Ministry of Housing, Spatial Planning and the Environment (VROM) had been conducted by Ecofys and VHK in 2009 to look at the financial effectiveness of a number of policy options in terms of € per saved GJ (M. Hoogwijk et al, Possibilities for additional appliance policy, december 2009). One of those measures is now being carried out.

VHK made scenarios for how this could develop until 2020, in a BAU (Business As Usual) scenario, a European Policy scenario, and in a BAT (Best Available Technology scenario. BAU and BAT are shown in figure 2a and 2b, respectively.



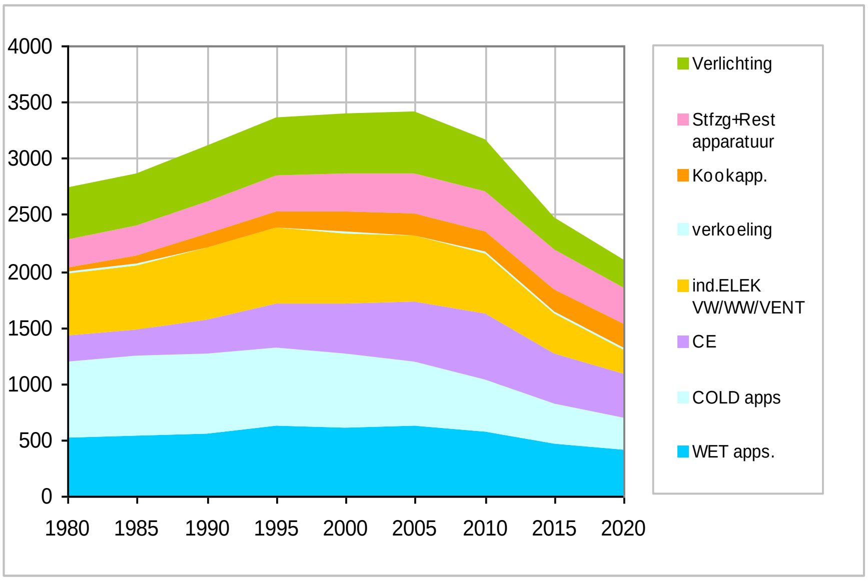


Figure 2 historic and (from 2005) modeled household electricity consumption, a) in a BAU scenario, b) in a BAT (Best Available Technology) scenario, by VHK, 2008[ii].

VHK concluded that, due to European regulation (Ecodesign and Energy Labelling), 11% could be saved in the period 2005 – 2020 with respect to the BAU scenario. If all households would start buying the best available technology in 2005, a whopping 34% could be saved by 2020. This clearly indicates the huge potential for savings.

A study for the Ministry of Housing, Spatial Planning and the Environment (VROM) had been conducted by Ecofys and VHK in 2009 to look at the financial effectiveness of a number of policy options in terms of € per saved GJ[iii]. At that time, promising measures identified were:

- A recycling bonus for turning in old appliances
- Showing energy costs of large appliances, computers and TV's in stores
- A heat pump stimulation programme

- A covenant on complex set top boxes

Figure 3. The Energy Indicator: Energy costs of appliances visible in stores.

One of those measures, showing the energy costs of large appliances in stores, is now being carried out. It is called the 'EnergieWeter' ('The Energy Indicator'). The project is managed by retail branch organization Uneto-VNI, supported by Milieu Centraal, an independent organization aiming to give consumers information on energy and environment. The Energy Indicator reports average annual energy costs in euros for white goods, televisions and computers. These costs are visible in stores and in web shops, enabling consumers to compare between appliances types and taking energy costs into account in their decision to buy. The majority of stores in the Netherlands participate, 1600 altogether.

Of other proposed measures, a recycling bonus for turning in old appliances was considered. However, this has not happened, amongst others due to a change of government.

In the following, recommendations on how to increase savings are discussed.

Recommendation 1: provide feedback

A lot has been researched and written and discussed in the area of consumer feedback. One literature review shows that direct feedback about energy consumption, e.g. via a display, can lead to savings of 5-15%[iv]. Another review shows that the more direct the feedback, the greater the savings, as is illustrated in figure 4.

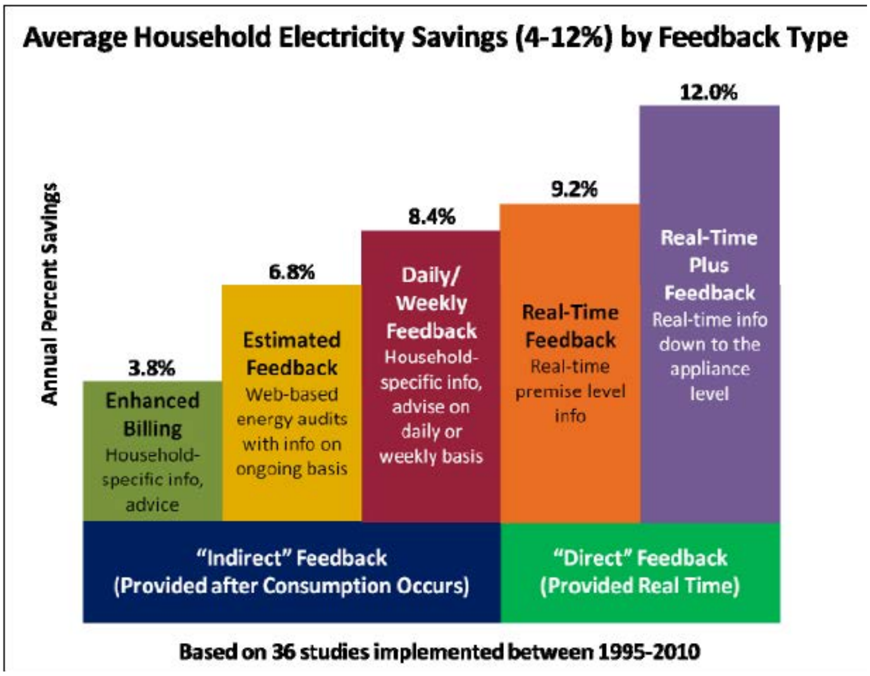


Figure 4. Annual percent savings versus way of feedback[v].

Even without electronic support, savings can be made – but these are limited to 3-4%.

In the Netherlands, a recent study by utility Nuon showed 9% savings of a group of 18 households with a display compared to 2% of the control group of 18 households without a display[vi]. Another utility, Oxxio, is currently running a practice trial with 6000 households.

A natural question to ask is how persistent these measured savings are. This has also been addressed by several investigators. The literature review of Darby says the following on this matter:

“Persistence of savings will happen when feedback has supported ‘intrinsic’ behaviour controls – that is, when individuals develop new habits – and when it has acted as a spur to investment in efficiency measures. People may need additional help in changing their habits – this is where well-thought-out energy advice can be of use. Where feedback is used in conjunction with incentives to save energy, behaviour may change but the changes are likely to fade away when the incentive is taken away. As a rule of thumb, a new type of behaviour formed over a three-month period or longer seems likely to persist – but continued feedback is needed to help maintain the change and, in time, encourage other changes.”[iv]

All in all the picture emerges that displays in combination with improved billing can really make a difference.

The Dutch government has decided in principle to implement the ‘smart meter’ based on a European directive (April 2010). However, only very limited attention has been paid to feedback in this system.

To correct this, the working group advises to

- Ensure that a direct feedback system is included simultaneously with the installation of the smart meter (this will also increase acceptance by the consumer).
- In the meantime, stimulate the use of other feedback systems already on the market (e.g. via energy bill).

In addition, more attention should be paid to stimulate the development of feedback systems for individual appliances. This will increase the effectiveness of the feedback.

Who should be made responsible for implementing feedback systems should be a topic of further research. The energy supplier could be a candidate, because he has a direct relationship with the consumer and can therefore link the feedback to other commercial products aimed at energy saving. An energy supplier also has an incentive for cost-effective implementation. On the other hand, consumers can switch from energy supplier, rendering any hardware installed unusable. That would vote for making the network company responsible.

Recommendation 2: yearly campaigns

Innovations in area of electrical equipment are often incremental, but sometimes huge leaps can still be taken. In a few instances, new technologies have been available for a while, but their market share is still relatively small. This currently applies to:

- Heat pump tumble dryers
- LED TVs
- Electric boilers with a heat pump
- Central heating pump with A label
- Efficient vacuum cleaners

It is recommended that a few of these possibilities are selected every year and focus special attention on them.

The campaign could consist of:

- Mass and multi-media campaigns
- Special focus in shops and other outlets

- Discounts for ‘fast decision-makers’

The aim of the campaign must be: market transformation. Once over, the market must switch permanently to the more efficient product.

The initiative can lie with the public sector, branch organisations, environmental organisations and/or consumer organizations.

Recommendation 3: Early Warning System

When the set top box was introduced, enabling consumers to receive digital TV, each of those boxes consumed 10 – 20 W of power continuously. The market share of these boxes increased to 60% of all households in a few years time, causing an additional power consumption on the order of 50 MW in the Netherlands. Nowadays simple set top boxes are regulated by Ecodesign, estimated to give more than 60% savings Europe wide. For complex set top boxes an Ecodesign implementing measure is in the making.

This examples illustrates how new appliances can come on the market and quickly gain market share before European regulation can catch up with it. There are currently no mechanisms in place to prevent this from happening again. More effort should be taken to prevent such energy guzzling unregulated appliances to gain a large market share. Therefore, the working group recommended putting in place an ‘Early Warning System’. The organization of such an early warning system (EWS) is schematically depicted in figure 5.

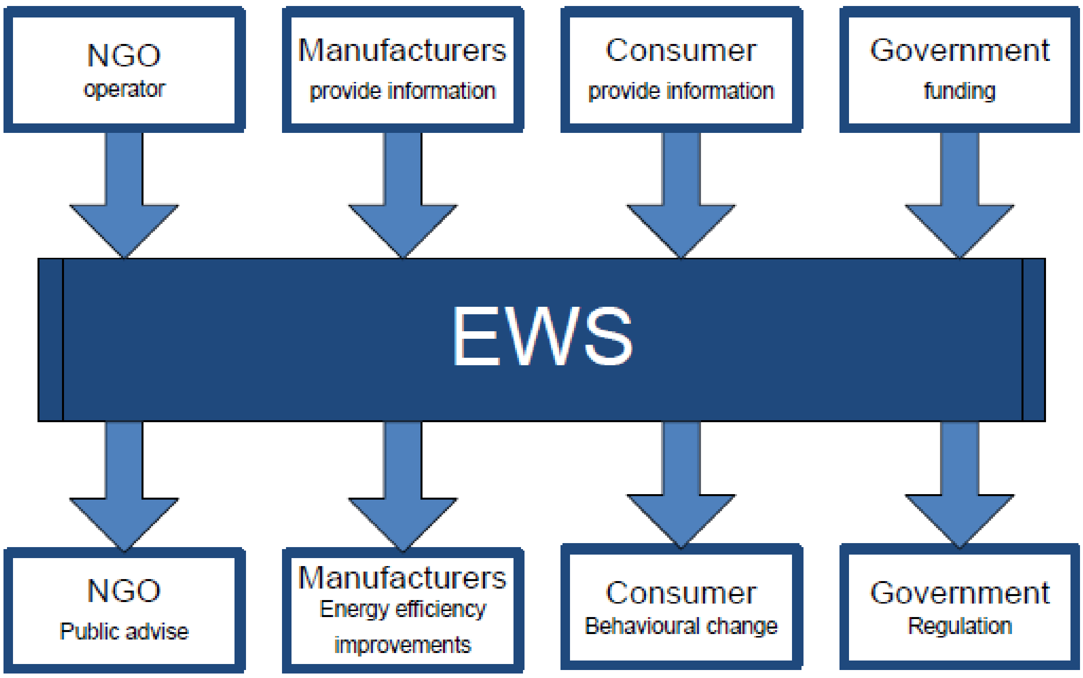


Figure 5 Schematic drawing of how an Early Warning System (EWS) for new energy guzzling appliances could work.

The task of coordination should be assigned to an independent body (NGO). Multiple parties should be involved in the generation and communication of warnings. Manufacturers could provide information, consumers could provide information. Regular inventory of energy consumption of new appliances can be done. When a warning is generated, various actions could be done. First and foremost, discussions with the manufacturer(s) should be started. In addition, action should be taken to start regulation on EU level. Third, consumers could be warned.

Such an institution could also function at EU level rather than country level.

Recommendation 4: improve information at retail level

The mandatory European labelling system requires labeling for all big appliances. This enables consumers to take energy consumption of appliances into account in their purchase decision. However, this does not mean that all consumers are now only buying the most efficient appliances. More is needed to further green their purchasing behavior. Salespeople in stores are known to be important influencers of consumer decisions. The level of information received from store personnel can vary strongly from person to person, and from store to store as well. This is shown in figure 6. This is the result of a small consumer survey, where students entered four large retail chains and labeled the information they received on energy as ‘ positive’, ‘neutral’ or ‘negative’. BCC is known to put efforts into personnel training on this subject, and judging from the figure this certainly has results, scoring better than the others. On the other hand, even there is still room for improvement. BCC also carries its own label for energy efficient appliances ("Groene Stekker" - Green Socket).

Information through internet is also improving, for example with consumer comparison sites. One such sites reports the HIER logo, that targets the top 10% in appliances. Another site enables consumers to sort on energy consumption as well as on label of white goods and TV’s.

The implementation of the ‘Energy Indicator’ was already mentioned.

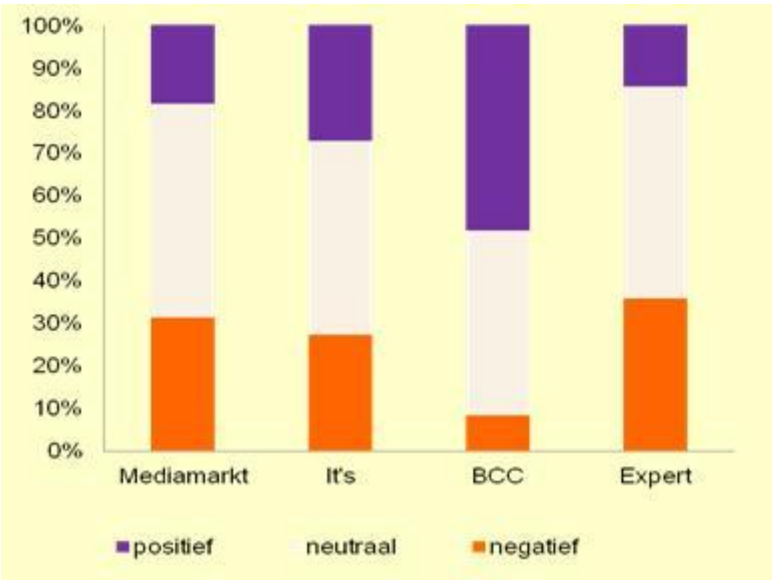


Figure 6. The importance of personnel training. In this figure the extent to which retail personnel can provide information about energy[vii].

This shows that efforts are already taken by retailers and branch organization. However, by no means all appliances are sold via the popular retail chains. For example, many dishwashers are sold as part of a kitchen. In this situation, energy efficiency or appliance labels barely come into play in the purchase decision, because it is a package deal and attention of the consumer (and salesperson) is concentrated on other issues.

About 8% of all appliances are now sold through internet. This share is expected to rise in the future.

It can be concluded that in order to inform consumer better on energy efficient appliances, efforts should be taken to improve information in all sales channels. Personell training is crucial in this matter. Non-traditional outlets such as the internet, kitchen suppliers, do-it-yourself (hardware) stores should get attention as well.

The initiative for this can be taken by branch organisations, government, possibly NGOs.

Recommendation 5: system approach in legislation

Legislation should also pay particular attention to electricity consumption. Extra savings are possible via a systems approach. Current legislation provides no impetus for improvements.

In many cases electricity consumption is not just determined by the efficiency of the components but of the total system.

Examples:

- Light bulbs have an energy label, but almost all are fitted in a lighting fixture. The combination determines the final effectiveness.
- The efficiency of the solar boiler can be increased by using hotfill for dishwashers.
- Household layout (including kitchen, heating installations) could be more effective. This is not taken into consideration due to the lack of criteria and rating.

System optimisations can probably contribute to meeting building regulations. This needs to be further investigated. Information on system efficiencies (e.g. of lighting fixtures, heating installations, ICT systems) should be published.

The general recommendation is that system solutions are initiated and should be rewarded in e.g. energy standards for buildings.

Conclusions

Given the total potential for savings in the household sector, the savings potential when better feedback is implemented in addition to the remaining measures, it is reasonable to estimate that the proposed recommendations can lead to at least 10% in savings in electricity consumption (350 kWh per household per year) for households annually. The combination of feedback in combination with various forms of improved information to consumers will strengthen each other.

The measures formulated do not involve huge government spending. They do require active participation and commitment from companies, institutions as well as the government.

Acknowledgements

The authors wish to express thanks to the members of the core working group:

- Wouter Leibbrandt (NXP)
- Ivo Opstelten and Niels Sijpheer (ECN)
- Ton Spoor (VEMW)
- Sible Schöne (Climate Agency)
- Wouter Wienk (AgentschapNL, secretary of working group)

References

[i] Communication with J. Gerdes, ECN, November 2010.

[ii] Van Holsteijn en Kemna 2008. See also: HP Siderius, M. van Elburg, 'The impact of Ecodesign measures on household electricity consumption in the Netherlands: even more savings are possible', EEDAL 2009, 156.

[iii] M. Hoogwijk et al, Possibilities for additional appliance policy, Ecofys, PEUENL084283, December 2009.

[iv] S. Darby: The effectiveness of feedback on energy consumption, Environmental Change Unit, University of Oxford, 2006.

[v] Ehrhardt-Martinez et al.: Advanced Metering Initiatives and Residential Feedback Programmes, ACEEE, Washington D.C., 2010.

[vi] L.T. Firet: Directe feedback energiegebruik helpt bij energiebesparing, TU Eindhoven, 2009.

[vii] Presentation Electricity Reduction, National Thinktank, Oct. 2009.

Israel's National Energy Efficiency Program: Reducing Electricity Consumption 2010-2020

Eddie Bet Hazavdi

Ministry of National Infrastructures Department of Energy Conservation. An expert on energy efficiency, a member of the energy forum at the Neaman institute, A member at the energy committee of the Israeli standard institute, a member of the environmental committee standards, chairman of the energy section of the green building standards a member of the Israeli solar association A member of the ISES (I Solar Energy society).

Abstract - **Israel's National Energy Efficiency Program: Reducing Electricity Consumption 2010-2020**

As in every modern country, the usage of electrical appliances in Israel is high. Yet, a comparison between Israel's current electricity production capacity and its electricity consumption reveals a state of chronic shortage. Unless we undertake immediate actions, we will experience an "electricity drought" already by 2013.

A year ago the government decided to reduce 20% of the total electricity consumption by 2020.

A National Energy efficiency program proposed recently has been confirmed by the government and the ministry. The program analyzed all the means that might contribute to reduce electricity, as well as electricity consumption by appliances. This includes consumer behavior and economic analysis. In the end a set of activities that should be taken including regulations enforcement and financed program was proposed. The ministry and the government agreed upon the program and have already taken some measures to implement the program.

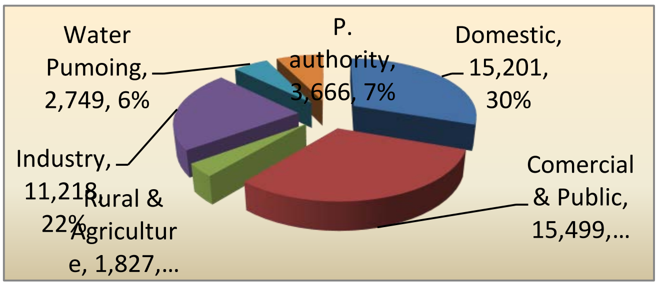
The program shows a possible of 47.2 % reduction (of the 20%) due the domestic sector.

In my paper I will present the domestic sector in Israel the methodology of the program the conclusion and the means that should be taken. I will also present some outcomes from pilot programs based on the national program

Introduction

Primary Energy consumption in Israel is about 26 Million TOE about 54% of the primary energy in 2008, went to produce electricity. Electricity in Israel produced from: 69% coal 22% Natural Gas 6% gas oil and 6% Harvey full oil (however Electricity consumed in Israel: 55% coal 40% Natural Gas 5% full oil and Harvey full oil). The number of population in Israel is about 7.2 million inhabitant total of 2.2 Million house holders Israel grow by additional 60K families every year. Electricity consumption in Israel is about 50 billion kWh distributed as such: 30% for domestic 31% for public & commercial 31% Authority 7% water pumping 6% industry 22% rural villages and agricultures 4%. The electricity consumption per capita is about 6600 KWh the electricity consumption per household is 6841 kWh GDP per capita in Israel in 2008 was about 25,000 US$. Lately Israel's average growth is about 3.5% annually.
Israel Has energy efficiency regulation for 6 appliances + another 4 (set-top box, lighting, TV, stand-by) are waiting to be confirming at the parliament.

Distribution of electricity consumption



The necessity to invest in energy efficiency.

The growth in population and in standard of living, along with the rapid growth of the Israeli economy over the last decades, has led to an increase in electricity consumption. However, the increase in electricity demand was not sufficiently met, as no new power plants have been built during the last years.

The economic and environmental cost of building additional power plants, in order to increase the production capacity of Israel's electricity economy, is expected to be significantly high. It involves the allocation of land resources; the purchase of fuels, hence the increase of Israel's geo-political and economic dependency on international markets; capital raising and its derived financing costs; air pollution; and increased greenhouse gas emissions. Not to mention the growing evidence about the depletion of crude oil and other fuel reservoirs. In addition, Israel faces a very serious land allocation limitation, due to its low availability of land.

In view of the aforesaid, the national effort to reduce electricity demands should be enhanced. By adopting energy efficiency measures, energy demands will be reduced, as will the scale of electricity production facilities which would otherwise be required. This would lead to a direct reduction in current-costs due to the decrease in energy costs economy-wide. This decrease would be reflected in reduced fuel use and a subsequent decrease in environmental pollution and national dependency on fuel import. The efficiency measures will increase economic stability, as a result of the decreased impact of fuel price and foreign market fluctuations on the Israeli economy and it will also decrease production unit emissions

Understanding the benefit of energy efficiency processes for the economy and the urgent necessity to implement them, the government decided on September 18th 2008 (decision no. 4095) to carry out cross-sectional efficiency measures, which will lead to a 20% reduction in electricity demand by the year 2020. However, this decision relies chiefly on private financing and on the effect of market forces.

To have a clearer perception: the saved costs resulting from the suggested efficiency measures are equivalent to the investment which would otherwise be required for the construction of additional power plants, in order to increase production capacity, and such an investment would also be financed by the public of consumers via an increase in electricity tariffs.

The effective implementation of the government's decision to promote energy efficiency in the Israeli economy, and to reduce future energy consumption by 20% until the year 2020, requires designated public financing. Such financing would make it possible to allocate the resources required for the efficiency process in the different sectors, and it would be aimed to change electricity consumption habits among consumers and move them to take practical steps in this direction, as specified below.

Work purpose

The purpose of this paper is to assess the extent of energy efficiency that can be attained in all sectors; and as a consequence – the energy efficiency programs that should be actualized until the year 2020. In this paper I will be focused on the domestic sector.

Methods

The assessment of attainable energy efficiency was performed for each and every sector of Israel's economy. The potential for increased efficiency was analyzed for the various energy systems of each sector, in view of its unique characteristics. The extent of economy-wide efficiency was assessed "bottom-up" – meaning, by adding up the rates of energy efficiency in each sector, according to its unique characteristics and the best practice technology available in the Israeli market.

Principles in the analysis process

The energy efficiency analysis was based on **changes derived from the use of more efficient energy systems and electrical appliances** by consumers in the different sectors – i.e. a result of regulatory changes, and of the provision of incentives for accelerating and advancing the replacement of ageing inefficient appliances with new and efficient ones among disadvantaged population, etc. – as well as on **consumer behavior derived changes**, reflected in the way the electrical appliances are used.

The efficiency objective has considerable economic implications on Israel's economy. The following are the factors that might obstruct its attainment:

♦ **A technological obstruction** – does not exist. The entire analysis was based on applicable and customary technologies.

♦ **An economical obstruction** – The implementation of the government's decision, requiring a 20% decrease in electricity consumption by 2020, is subject to the successful attainment of financial sources that will facilitate the execution of the efficiency programs. This acutely requires the immediate creation of an energy efficiency fund, or the allocation of designated financial sources within the state budget.

The analysis is based on the most updated data and tariffs, derived from the 2008 statistical reports of the Israel Electric Corporation the Central Bureau of statistics Israeli Standards, the Israeli regulations

Analysis conclusions for the domestic sector

The effort to reduce energy demands must be **fundamentally** increased. Energy efficiency measures will reduce energy demands and restrict the scale of electricity production facilities which would otherwise be required; it will also reduce fuel use and restrict the national dependency on fuel imports, as well as reduce emissions and decrease environmental pollution**.**

Establishing an **energy efficiency fund**. This can be achieved by taxing essential service providers, and embodying these added funds in the consumer tariff

Increasing governmental enforcement,

Increasing the number of professionals

Changes in regulation and standardization are highly important for achieving the efficiency objective. Regulation changes should be introduced **as soon as possible** for electrical home appliances and for energy systems in the industrial and commercial-public sectors. In parallel, an enforcement mechanism should be established within the frame of the Energy Conservation Department in the Ministry of National Infrastructures. This enforcement mechanism would supervise electrical appliances and energy systems, and ensure their compliance with the required efficiency levels.

Enhance the use of taxing mechanisms tax reduction for A & B appliances taxation of C-G appliances.

Initiating an appliance replacement and removal of old appliances from all households by bids and refund for new more efficient appliances.

Offer of financial incentives for socio-economic disadvantaged populations, in order to encourage the replacement of old and inefficient electrical appliances with new and efficient ones.

Lighting - It should be mentioned that the replacement of incandescent light bulbs with economical bulbs has a great efficiency potential. It is advisable to allocate the appropriate budgets – **as soon as possible, in 2010 already** – for bulb replacement economy-wide, and at the same time forward legislation changes to prohibit the importation of inefficient bulbs.

Carry out public information programs to increase awareness regarding the importance of energy efficiency - to induce changes in consumer behavior, in terms of "smart purchase" of energy efficient products, as well as of a more efficient and controlled electricity usage

Carry out a structured educational program along with the ministry of education – to increase children awareness towards energy saving and 0 emission energy.

The efficiency incentives will be focused on the upgrade of existing systems, and on the acquisition of new systems having a high efficiency rate. In the allocation of large scale incentives, preference will be given to projects which reflect a higher efficiency rate. Preference will also be given to efficiency programs which promote the **use of residual heat as a source of energy.**

The Efficiency Program in the Household Sector

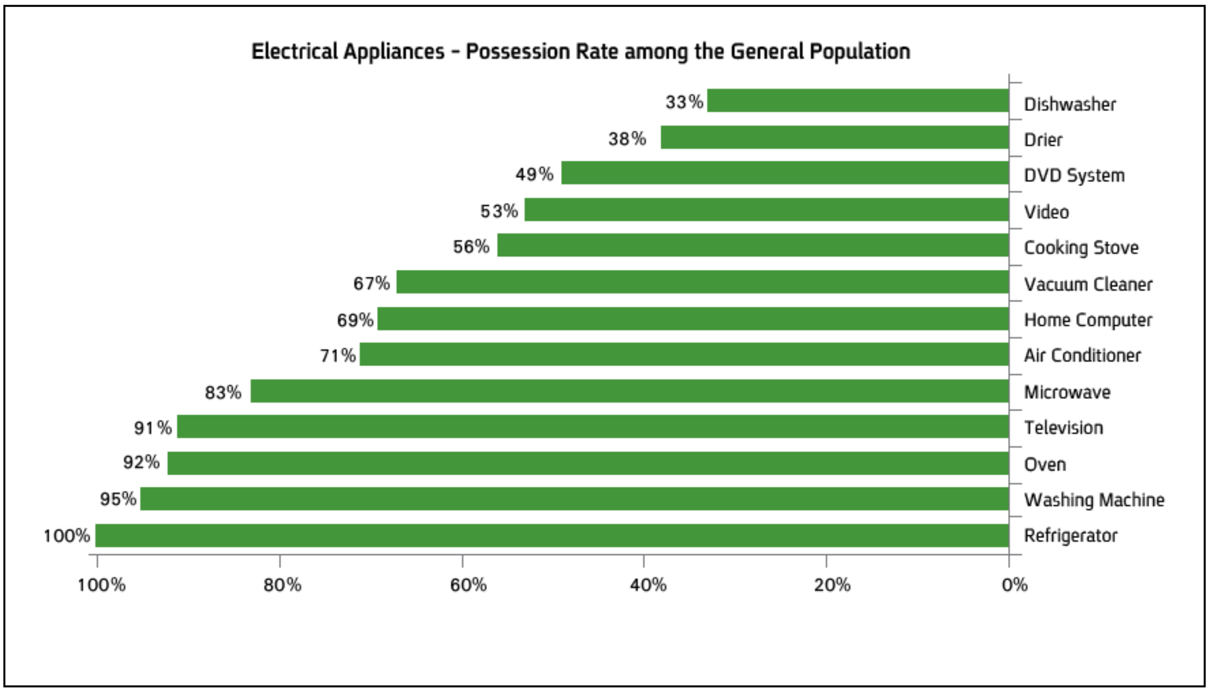
In 2008, electricity consumption in the household sector summed up to about 15.2 billion kWh, comprising approximately 30% of the total electricity consumed in Israel[8]

This sector saw an annual increase of about 3.5% in electricity consumption between the years 1999-2008[9] since 1999 it grew by 151%. If energy efficiency measures are not adopted, electricity consumption of the household sector is expected to reach about 23 billion kWh by 2020[10]. The 20% required optimization in electricity consumption in the household sector, in accordance with the September 2008 government decision, is expected to save approximately 4.5 billion kWh by the year 2020, in this sector only.

In addition, the domestic sector contributes about 32% of the total electricity consumption during summer peak demands and about 49% of the total electricity consumption during winter peak demands[11]. An optimization of at least 20% in electricity consumption will reduce the contribution of the household sector to the total consumption during peak demands by a similar rate at least.

The domestic consumption sector uses dozens of electrical appliances routinely.

The following are the penetration rates of the main appliances among the Israeli households[12]:



Principles in assessing the energy efficiency level of electrical home appliances

When we come to assess the annual saving which may be created as a result of the examined efficiency programs[13], we must refer to the existing gap, at the level of the individual appliance, between the annual consumption of an efficient electrical appliance and that of an inefficient one.

[8] Based on data of the Israel Electrical Corporation – 2008 statistical report

[9] Based on data of the Israel Electrical Corporation – 2008 statistical report

[10] Based on data of the Israel Electrical Corporation – 2008 statistical report

[11] Based on data of the Israel Electrical Corporation – 2008 statistical report

[12] Based on data from the Central Bureau of Statistics;

[13] The efficiency programs will include, among other things, the consolidation of legislation for electrical appliances, initiated replacement programs for electrical appliances, etc

It is appropriate to derive the term "efficient electrical appliance" from the regulations which refer to the efficiency level of electrical appliances[14]. Some of these regulations have been created during the past few years, and others are worked on these very days. The regulations are partly based on standards from 2004, which rely on data from the beginning of the 2000's. It should therefore be examined whether the required efficiency levels in the current format of the regulations internalizes the technological developments which have occurred since the standards (on which the current regulations rely) were established. The regulations are examined according to the electricity consumption of electrical appliances which were either imported or made in Israel, and they refer to the most technologically advanced appliances that exist today.
It should be verified that the requirements which are defined in the regulations can effectively restrict the electricity consumption of the different appliances, meaning that:
If 90% of the appliances will still be sold, despite the regulations and within their framework – then the regulation cannot bring a real reduction of consumption levels.

On the other hand, if only 20-30% of the models of a specific appliance comply with regulations, then it will be impossible to meet the regulations.

It should be mentioned that apart from the consolidation of regulations, there is a parallel need to stay constantly updated in terms of technological developments – i.e. to identify efficient parameters of electrical appliances in Israel and abroad, in order to examine future technological developments which may have an impact on the maximum consumption level of the appliances.

Review of Regulations

The effectiveness of the Regulations (which refer to electrical appliances used by the household sector[15]) will be reviewed in accordance with the following parameters:

- The maximum electricity consumption required for an electric appliance according to the present regulations.
- The average electricity consumption of an electric appliance which has either been imported or manufactured in Israel during the last years[16].
- The average electricity consumption of new models of an electric appliance, which were authorized by the regulations during the last years.

An evaluation of this data should provide:

- The maximum electricity consumption that should be requested within the regulation (if the required changes take place), in reference to consumption level of the most efficient appliances that exist today.
- An assessment of the prospected average electricity consumption level of specific electric appliances in the next decade.

It should be emphasized that due to the lack of sufficient manpower to enforce the regulations of energy ratings in some appliances, we have to rely on the producer/importer declared energy rating (e.g. to ensure that manufacturers don't give an A rating to an electric appliance which exceeds the required standard consumption)[17]. It is essential to set-up an efficient enforcement system, in order to facilitate the use of efficient electrical appliances, as displayed below**.**

[14] "Regulations" – The regulations for minimum energy efficiency, or for maximum electricity consumption of specific electric appliance;
[15] Based on the content of the regulations, as it is published on the website of the Ministry of National Infrastructures.
[16] 2007 data of the Association of Industrialists and Importers and the Office of Standards and Regulations
[17] The producers' declaration also requires the approval of the Office of Standards and Regulations. However, it should be emphasized that the Office does not determine the level of minimum energy efficiency.

The following table displays data assessment results for electricity consumption of specific electrical appliances:

Dishwashers – data per cycle	Clothes Dryers – data per kg	Ovens – data per cycle	Washing Machines – data per kg	Air[18] Conditioners – data per hour	Refrigerators – data per 24 hours	Electricity consumption levels per specific appliances
1.3	**0.67 – dryers with an exhaust pipe, 0.73 – dryers with a condenser[12]**	**0.88 up to 35 liters , 2.1 above 35 liters[21]**	**0.21**	**1**	**2.3**	**Maximum electricity consumption according to the present regulations (in kWh)**
2010	2010	2010	2010	2009	2007	Most updated regulations became effective on (year)
1	0.56 – dryers with an exhaust pipe, 0.67 – dryers with a condenser	0.82 up to 35 liters , 0.92 above 35 liters	0.18	0.9	1.8	Average electricity consumption of appliances which has been imported or manufactured during the last years (in kWh)
0.8	0.6[22]	0.88[21]	0.16	0.8	1.5	Average electricity consumption of new models (in kWh)
1	0.56 – dryers with an exhaust pipe, 0.67 – dryers with a condenser	0.85 up to 35 liters , 0.9 above 35 liters	0.185	0.9	1.8	Maximum electricity consumption adequately required under the regulations (in kWh)
0.8	0.6	0.88	0.16	0.85	1.5	Evaluation – average electricity consumption by 2020 (in kWh)

[18] Date refer to 'air conditioners per room'. As specified below, it is assumed that every household contains, on average, 0.5 air conditioners per room.
[19] About 90% of imported ovens have a volume of 35 liters or more (2007 data).
[20] About 50% of imported clothes dryers have an exhaust pipe, and about 50% have a condenser (2007 data).
[21] A weighted average of electricity consumption data in new models of ovens, over and under 35 kg;
[22] A weighted average of electricity consumption data in new models of clothes dryers, with an exhaust pipe or with a condenser;

It can be safely assumed that the gaps in the energy efficiency levels of electrical appliances will be (partly) embodied in the price of the appliance and imposed on the consumers. This refers to the differences between the consumption levels that are indicated in the regulations and the consumption levels following the introduction of necessary updates.
The maximum cost gap for specific electrical appliances was assessed according to the electrical appliances' scope of operations, as described below in section 4 of this chapter**:**

- Values below the maximum cost gap mean that the investment in regulation change during the present period is lower than the financial saving flows (capitalized) which will be received as a result of the change in regulations – and therefore the change in regulations is economically profitable;

- Values above the maximum cost gap mean that the investment in regulation change during the present period, which will probably be imposed on the consumers, is higher than the financial saving flows (capitalized) which will be received as a result of the change in regulations – and therefore the change in regulations should be re-examined.

The following table displays the economical efficiency threshold (in NIS) for consumers according to the regulation change (the maximum cost gaps for specific electrical appliances, in which economical efficiency is still maintained, in light of the forecasted saving flows that will be achieved along the appliance's life span):

Conclusions from the review of regulations:

The following are the conclusions derived from the table:

Dishwashers	Clothes Dryers	Ovens	Washing Machines	Air Conditioners	Refrigerators	
63	63	36	36	280	183	**Yearly energy saving due to regulation changes (in kWh)**
27	27	16	15	120	78	**Yearly financial saving (in NIS)**
461	461	23	96	2,061	618	**Maximum cost gap, embodying the regulation-change derived economical efficiency (in NIS)**

According to the economical review, the minimum energy efficiency/maximum electricity consumption parameter in the regulations should be updated for the following appliances: refrigerators[24], air-conditioners, clothes dryers and dishwashers.

- It happens sometimes that the regulations cannot catch up with technological developments, and as a result – some of the regulations become ineffective. As regards to washing machines and ovens, the present value of the expected saving flows – which will result from the initiated change in regulations – is relatively low.

[23] The change in washing machine regulations refers only to electricity consumption levels. In the event that the regulations regarding the use of hot water (described below) are changed as well, a 30% decrease in electricity consumption of washing machines will be feasible, and the present cost gap value in appliance price will consequently rise to 310 NIS.
[24] Refrigerators are examined according to an average volume of 500 liters per fridge.

For some of the existing electrical appliances, the regulation determines the years in which an update to the maximum consumption level should be made. When one updates the regulations, he must ensure that the maximum electricity consumption level is not lower than that of most of the electrical appliances on the market.

- Currently, the energy rating of many electrical appliances (washing machines, ovens, clothes dryers, etc) which meet the regulation's requirements is between A to B or between A to C only. This means that a broad range of different electricity consumption levels are cataloged under the same energy rating.

  It is recommended to renew product rating, and have products graded between Categories A to G (without relying on the European Standard). This would provide consumers with a proper tool with which they can compare the energetic efficiency of electrical products.

  The Washing Machine Regulations – another required change:

  Today, washing machine dual-connection (hot and cold water) regulations exist for structures, within the framework of the Planning and Construction Regulations[25]. On the other hand, the present washing machine standard doesn't require a hot water connection.
  Due to the fact that electricity consumption of washing machines in mostly used for heating water, the present standard should be changed and allow for an additional hot water connection. This would bring a future saving of at least 30% in washing machine electricity consumption.

- **Television Set Regulations (consolidated in 2010):**

  The electricity consumption regulations for television sets are being consolidated these days. Hence, the present regulations reflect the proper electricity consumption under the technological developments. However, **measures should be taken to apply an energy rating that varies between categories A to G for this appliance as well.**

- **Computers:**

  There is no need to create specific regulations for computers, as the technology involved in this appliance is currently ahead of legislation.

- **Solar water-heaters with an electricity back-up:**

  Water heaters can be economized by reducing water-scale, which requires the installation of compatible filters.
  It is not economical to regulate the installation of filters, as not much electricity is saved by this measure (annual saving of 80-400 NIS for the use of electricity as a back-up for the solar function; reduction of 20% in electricity consumption due to filter installation) compared to the scope and frequency of its related expenses (about 800 NIS for filter installation and technician work; filter should be replaced once a year).

- **Stand-By Loss Regulations (consolidated in 2010):**

  Various electrical appliances also consume electricity while on stand-by mode (when the appliance is not operated). Stand-by consumption comprises about 5% of the total consumption in the household sector, and about 3% of the total consumption in the commercial-public sector.
  In 2010, we created regulations aimed to reduce 'stand-by' electricity consumption by 80%.
  It should be emphasized that the existing technology for reducing 'stand-by' consumption is highly prevalent in developed countries, and it is not supposed to substantially raise appliance prices.
  The effect of the 'stand-by' consumption regulations will be analyzed below.
  It is recommended to indicate the 'stand-by' electricity consumption rate on the appliance's information label.

[25] The regulations entered into force about 3 years ago.

4. The extent of energy efficiency for specific electrical appliances

When we come to examine how to achieve optimal energy efficiency for each electrical appliance, we must first review the extent of absolute electricity saving in each and every appliance, based on the efficient-consumption level which was reviewed in section 3 above.
When we weight this data with the household sector penetration rate of each electrical appliance, it helps us to evaluate the extent of efficiency that can be achieved through the application of the energy efficiency threshold regulations.
When a certain product's extent of efficiency is significant, it should be examined whether the implementation of the electrical appliance replacement programs is feasible, as described below.

The extent of efficiency will be examined by carrying out a Pareto analysis of the expected efficiency level, followed by an analysis of the expected efficiency of appliances which occupy a high or medium share of household electricity consumption. Therefore, this document does not display the regulation-derived efficiency scopes for vacuum cleaners, cooking stoves, microwaves and video or DVD systems, which are used focally and limitedly, for a relatively short time. Still, **Minimum energy efficiency regulations should of course be validated for these electrical appliances as well**.

The extent of efficiency in annual electricity consumption for specific appliances will be established according to the following parameters:

- ♦ Average electricity consumption in old, energy inefficient appliances.
- ♦ Average electricity consumption in appliance which were either imported or manufactured in recent years (for the years 2010-2011).
- ♦ Average electricity consumption in new, energy efficient appliances, in compliance with regulations (for 2012, onwards).
- ♦ Number of operating hours or cycles per 24 hours.
- ♦ Number of electrical appliances of the same type in an average household.
- ♦ Yearly reference – number of operation days per year.

There is a gap between electric appliance average electricity consumption in the years 2010-2011 and between the average consumption in 2012 onwards, in correlation with the date in which the regulation change becomes effective:

The proposed change in regulation is expected to be approved on 2011, following a related intensive activity taking place since mid 2010. However, since importers and suppliers need some time to organize logistically for the importation and production of the new and efficient appliances, it is assumed that if the related intensive activity continues, the regulation change will take effect in 2012. Therefore, the consumption data until 2012 will be based on the electricity consumption data in appliances which have been sold over the last years (according to the older regulation). Beginning in 2012 onwards, the regulation change will be weighted in the consumption data, as required above.

The following are the working assumptions for the purpose of data weighting:

- ♦ Efficiency scopes are examined in the following appliances: Refrigerators, air conditioners, washing machines, ovens, television sets, clothes dryers and dishwashers (at the level of an individual appliance).

- ♦ <u>Air conditioners</u>: 280 days of acclimatization activity (cooling and heating) per year; 5 hours of activity per day; 0.5 air conditioner per room in an average home, over the next decade. Average electricity consumption prior to the application of the energy efficiency regulations – 40% of installed air conditioners consume on average 2 kWh per hour; the remaining 60% consume on average 0.8 kWh per hour.
- ♦ <u>Washing machines</u>: Assuming 5 operation cycles per week; 5.5 kg on average per cycle.
- ♦ <u>Ovens</u>: Assuming 2.5 operation cycles per week.
- ♦ <u>Television sets</u>: Assuming 2.5 hours of operation on average per every home television. Today, there is an average of 2 television sets per home. It is assumed that from the middle of the next decade, this will rise to an average of 3 television sets per home.
- ♦ <u>Clothes dryers</u>: Assuming 2.5 operation cycles per week; 6 kg on average per cycle.
- ♦ <u>Dishwashers</u>: Assuming 4 operation cycles per week.

The following table displays the annual savings (in kWh) per appliance among the examined electrical appliances; both for the period of 2010-2011, before the updated regulations take effect, and for the period beginning in 2012 onwards, following regulation application:

Dishwashers – data per cycle	Clothes dryers – data per kg per cycle	Television sets – data per hour	Ovens – data per cycle	Washing machines – date per kg per cycle	Air conditioners – data per hour	Refrigerators – data per 24 hours	Extent of annual efficiency for individual electrical appliances
1	3.75	0.3	0.95	3	1.28	5	Average electricity consumption in old and inefficient products, **prior to regulations** (in kWh)
1	3.75	0.3	0.92	0.99	0.9	1.8	Average electricity consumption in new products, 2010-2011 (in kWh)
0.8	3.6	0.2	0.88	0.88	0.8	1.5	Average electricity consumption in new and energy efficient products, **in view of regulation change**, as of 2012 (in kWh)
0.57	0.36	6.25	0.36	0.71	10		Operation hours or cycles per day
0	0	0	0.01	1.4	3.8	3.2	Energy savings per operation day, 2010-2011 (in kWh)
0.11	0.05	0.63	0.03	1.5	4.8	3.5	Energy savings per operation day, **in view of regulation change**, as of 2012 (in kWh)
365	365	365	365	365	280	365	Annual reference – number of operation days per year
0	**0**	**0**	**4**	**524**	**1,064**	**1,168**	**Annual energy savings per household, 2010-2011 (in kWh)**
42	**20**	**228**	**9**	[27]**567**	**1,344**	**1,278**	**Annual energy savings per household due to the use of energy efficient products following the regulation change, as of 2012 (in kWh)**

[26] As aforesaid, the energy saving values for refrigerators and air-conditioners are only relevant in the case of disadvantaged populations, which are not subject to the effect of regulation. The 2010-2011 energy saving among the remaining households, which are affected by regulation changes, is zero. This will change following the consolidation of more efficient regulations, which are assumed to take effect in 2012.

[27] This value weights the change per average household due to the effect of hot water use in washing machines (it is a partial effect, because of the hot water connection restrictions in current construction work).

The table reveals that the application of the minimum energy efficiency regulations will lead to substantial energy savings, especially for refrigerators, air conditioners, washing machines and television sets. The remaining electrical appliances are expected to experience lesser savings. These four appliances are highly prevalent in the household sector, and therefore the importance of this data is even greater, as displayed below.

It should be emphasized that the Israel Electric Corporation's present demand forecasts (from mid 2009) internalize the regulations that were valid when the forecasts were prepared – i.e. the Refrigeration and Air Conditioning Regulations. Therefore, as far as these products are concerned, only the effects of additional efficiency measures, on top of those already included in the regulations, will be weighted.
Yet, the majority of disadvantaged population households are not influenced by changes in regulation, and therefore the Israel Electrical Corporation's forecasts, in which only the effects of regulation-change are internalized, do not include consumption changes in these households. Therefore, the full effect of demand reduction was weighted for these populations, i.e. from a state of 'pre-regulations' consumption, to a consumption level that complies with the updated regulations.

5. Anticipated decrease in demands following the application of the regulations:

After evaluating the annual scope of energy savings for individual appliances, it is required to determine the household penetration rate of the different electrical appliances, in order to evaluate the overall scope of energy efficiency. This evaluation should reflect both existing households and new household to be created until 2020.

The household penetration analysis of the different appliances should be based on the following parameters:

- **Household penetration of the appliance during 2010:**

  This is required in order to evaluate the effect of regulation on both existing households during 2010, as well as on newly created household during the next decade[28].

- **Annual increase rate in household penetration of the electrical appliance:**

  This is particularly relevant for electrical appliances which were commonly used during the last years (air conditioners, clothes dryers, dishwashers)[29], and less relevant for basic electrical appliances which were commonly used over the last decades (refrigerators, washing machines, etc).

- **Evaluating the period (in years) after which an old and inefficient electrical appliance is replaced with a new and efficient one:**

  Household electrical appliances are periodically replaced, based on various considerations such as wear and tear, technological developments or a personal interest in renewal. It is required to evaluate the number of years after which every electrical appliance is replaced with a new and efficient appliance, which is affected by regulation.
  The effect of regulation is expected to endure until after all the inefficient appliances are replaced in all households. Afterwards, an efficient appliance will be replaced by another efficient appliance (it is too early today to say what technological developments will be introduced in a few years time, and what will be their correlating electricity consumption). Therefore, the effect of current regulation on existing households, in light of the information that exists today, is expected to cease at a certain point.

[28] Based on data from the Central Bureau of Statistics;
[29] The annual increase rate evaluation was based on the increase rate in household penetration of these appliances over the last years, in light of the Central Bureau of Statistics' data.

There are two exceptions to this analysis – refrigerators and air conditioners. These two electrical appliances were already subjected in 2005 to initial regulation, which determined minimum energy efficiency levels for them. However, according to the recommendations of the updated regulations – appliances, which were replaced following 2005 need to undergo additional efficiency measures. Hence, when these appliances will be replaced at the end of their life span, their electricity consumption will be even lower. For this reason, a longer replacement period was adjusted for these appliances.
On the other hand, the effect of regulation will continue to be reflected on new households which will be created until 2020. The effect of regulation applies when the household is created, and it is therefore expected to endure also after the existing inventory of appliances is replaced.

In general, the effects of regulation cease after the entire existing inventory of inefficient appliances is replaced (excluding, as aforesaid, refrigerators and air conditioners). Yet, in the case of products which are subject to considerable technological developments, e.g. television sets, an assessment was made of future electricity consumption (also after the existing appliances are replaced), and this assessment was adjusted within the reduced demand model.

The replacement period of electrical appliances was evaluated according to their household penetration rate, life span, and local market supply data over the past ten years.

♦ **Rate of households with energy inefficient electrical appliances:**

The evaluation of households with inefficient appliances was based on the following data:

- Detailed data regarding the models of each electrical appliance which were sold over the last years, scopes of sale for the different models, and electricity consumption level per model.
- In the case of appliances on which the regulations were already applied, such as refrigerators and air conditioners – the year in which the regulations were applied on the appliance.
- The period after which the electrical appliance is supposed to be replaced, as indicated above – this refers to products on which the regulations were already applied.

This figure is relevant for existing households (and not for new households).

The effect of the new regulations on the self-purchase of electrical appliances will be moderate, because the regulations hardly influence households of socio-economic disadvantaged populations, which own these appliances.
Part of Israel's population[30] cannot for socio-economic reasons purchase new and efficient electrical appliances. Therefore, the effects of regulation following self purchase of electrical appliances are limitedly relevant to these populations. An option that should be examined, in order to promote energy efficiency, is to introduce regulated replacement programs for electrical appliances among these populations. For this end, the analysis should exclude at this stage some of the households of disadvantaged populations. Later on, the energy efficiency levels resulting from the replacement of electrical appliances among these households will be analyzed under the replacement programs.
It should be emphasized that the aforesaid exclusion will only be performed in appliances that may be included in replacement programs; i.e. it is not applicable to luxury products such as television sets, clothes dryers and dishwashers.

The following parameters should therefore be taken into consideration:

♦ **Product penetration rate in 2010, among populations with a low socio economic status:**

The rate of households of disadvantaged populations possessing a certain appliance is derived from the rate of families possessing that appliance[31].

[30] The size of household of disadvantaged populations was correlated to the number of households receiving income assurance.
[31] The number of income assurance recipients is identical to the number of households in the three lower echelons. Therefore, the penetration rate of electrical appliances was assessed for these echelons only.

- The rate of disadvantaged population households which will purchase new appliances without waiting for the replacement programs:

  As aforesaid, due to the low socio-economic status of disadvantaged population, it can only purchase electrical appliances at a very slow pace, meaning that the changes in regulation affect them at a very slow pace as well. However, it is safe to assume that when the use of certain electrical appliances will be banned, these households will not wait for the replacement programs to take effect and some of them would purchase the electrical appliances on their own. Such households would be affected by the new regulation, and should therefore be included in the said analysis.

- Number of disadvantaged population households not affected by regulation:

  This is consequential data based on the aforesaid: In order to calculate the number of households excluded from regulation-effect analysis, we should take the number of disadvantaged population households possessing the electrical appliance and deduct from it the number of households which will purchase a new product due to the banning of an old one.

The analysis was based on the following data[32]:

- Total number of households: about 2.2 million.
- Number of benefit recipient households (most of which would not take any energy efficiency measure without the replacement programs): about 670,000.
- Number of new households in 2009: about 60,000.
- Average annual growth rate in the number of new households: 6.5%.

[31] The number of income assurance recipients is identical to the number of households in the three lower echelons. Therefore, the penetration rate of electrical appliances was assessed for these echelons only.
[32] Central Bureau of Statistics data, end of 2009.

The following table displays the parameters affecting the extent of energy efficiency following regulation changes, by electric appliance:

Dishwashers	Clothes dryers	Television sets	Ovens	Washing machines	Air conditioners	Refrigerators	Extent of annual efficiency – electrical appliances
40%	40%	92%	94%	97%	75%	100%	Penetration rate in 2010
2.0%	0.5%	0.5%	0.0%	0.0%	1.5%	0.0%	Annual growth rate in product penetration
2010	2010	2011	2010	2010	2009	2008	Application date of the updated energy efficiency regulations
10	10	5	10	7	10	6	Evaluation of the number of additional years (from the beginning of 2010) until a new product enters the market
80%	80%	60%	80%	75%	85%	55%	Rate of households with a specific energy inefficient product
			85%	93%	52%	100%	2010 penetration rate among disadvantaged populations (benefit recipients)
			5%	15%	5%	20%	Rate of disadvantaged population households which will purchase a new product without waiting for the replacement program
			541	530	331	536	Number of disadvantaged population households in which the product exists and included within the framework of the replacement programs (in thousands)

The extent of energy efficiency for individual electrical appliances will be calculated according to the following consequential parameters:

- **Number of existing households (affected by regulations) in 2010:** This parameter takes into consideration the households which have energy inefficient appliances, the penetration rate of the appliances and the change in penetration rate until 2020. It excludes the number of disadvantaged population households which are not affected by the change in regulation.

- **Number of new households in which the appliance exists (which will be created each year until 2020):** This parameter takes into consideration the penetration rate of the appliance in new households, and the change in penetration rate until 2020.

- **Extent of energy efficiency due to regulation changes in each appliance, for a specific year:** Summing up of both existing and new households, and weighting this figure with the annual energy savings per household due to the use of an efficient appliance, as indicated in section 4 above.

- **Cumulative energy saving since 2010**

The following table displays an evaluation of the expected decrease in electricity demand in each year (in millions of kWh), due to **the change in refrigerator regulation.** It is hereby clarified that following figures are derived from the recommended additional modification in refrigerator regulation. The present refrigerator efficiency (or consumption) regulations were internalized into the Israel Electrical Corporation's demand forecasts since mid-2009.

As aforesaid, it should be emphasized that these efficiency objectives were determined based on the assumption that the refrigerator minimum efficiency regulations will already be applied in 2011, and become effective by 2012. In order to achieve this, immediate action should be taken to ammend the refrigerator regulations (as well as those of other electrical appliances), as recommended in section 3 above.

2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	Refrigerators
111	111	111	111	111	111	111	111	111	111	2010 regulation affected households – multi-year distribution (in thousands)
122	114	107	101	94	88	83	78	73	68	New households each year (in thousands)
25	25	24	23	22	22	21	21	20	0	Extent of annual energy savings per specific year (in millions of kWh)
203	**178**	**153**	**129**	**106**	**84**	**62**	**41**	**20**	**0**	**Total decrease in demands due to the change in refrigerator regulation (in millions of kWh)**

6. 'Stand-by loss' regulations – appliances' electricity consumption on 'stand by' mode

The consumption of household electrical appliances on stand-by mode is estimated at 5% of the overall electricity consumption in this sector.
The efficiency potential due to the regulation change is estimated at 80% of the electricity consumed in this mode, to be applied gradually over a period of 10 years. The change will rely on the purchase of new energy efficient electrical appliances[33].
The regulation will affect new electrical appliances which will be purchased by the household sector. Therefore, disadvantaged populations, for whom it is financially difficult to purchase these electrical appliances, are not weighted within the change.

The following table displays the expected decrease in demands by 2020, as a result of the regulation change (in millions of kWh)[34]**:**

2020	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	
1,148	1,110	1,072	1,036	1,001	967	934	903	872	843	Extent of annual consumption (in millions of kWh)
50.4%	44.8%	39.2%	33.6%	28.0%	22.4%	16.8%	11.2%	5.6%		Efficiency rate
579	**497**	**420**	**348**	**280**	**217**	**157**	**101**	**49**		**Decrease in demands as a result of the stand-by loss regulation change (in millions of kWh)**

[33] Average life span of an electrical appliance;
[34] Assuming that the application of the stand by regulation will begin in 2011 and the regulation will become effective (following supplier/importer organization, etc) in 2012;

7. Summary of demand decrease as a result of the regulation change in the household sector

The following table displays a summary of electricity demand decrease resulting from the regulation change in electrical appliances in the household sector (reviewing 7 appliances, in both operation and stand-by modes), and assuming that the regulation change will become effective in 2012 (in millions of kWh):

2020	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**Cumulative energy savings since 2010**
203	178	153	129	106	84	62	41	20	0	Refrigerators
515	449	385	323	264	207	153	100	49	0	Air conditioners
1,157	1,089	1,025	965	909	767	628	493	360	230	Washing machines[35]
17	16	14	12	10	8	7	5	3	1	Ovens
700	615	532	451	372	294	218	144	71	0	Television sets
18	17	15	13	10	8	6	4	2	0	Clothes dryers
43	40	35	29	24	19	14	9	4	0	Dishwashers
579	497	420	348	280	217	157	101	49		Stand by loss regulation
3,233	**2,901**	**2,579**	**2,270**	**1,976**	**1,604**	**1,245**	**896**	**559**	**231**	**Total decrease in demand due to regulation change (in millions of kWh)**

Our conclusion is that by 2020, a substantial saving of about 3.2 billion kWh[36] will be reached in the household sector, as a result of regulation changes relying on existing technological developments in different electrical appliances (in both operation and stand-by modes). The reduction in electricity purchase costs (capitalized)[37] for household sector consumers by 2020 due to this regulation change, has a present value of about 4.78 billion NIS.

8. Costs:

The total cost of regulation advancement and enforcement is 10 million NIS a year.

A. Preparation of standards, laboratory upgrade: About 5 million NIS a year.

The regulation operations require coordinated work with the Office of Standards and Regulations, in order to identify technological developments in electrical appliances, promote the preparation of standards, upgrade laboratories, etc.

[35] Assuming that regulation change will allow using hot water in washing machines, and weighting the average effect within the population.
[36] Not included in the current demand forecasts.
[37] Assuming a capitalization rate of 6%.

B. Creating an enforcement system: About 5 million NIS a year.

In general, the customs mechanisms are in charge of preventing the entry of inefficient electrical appliances into Israel. However, additional manpower is required in order to monitor the use of existing inefficient appliances which would be banned by regulations, such as chillers in the industrial, commercial and public sectors, water pumps, etc. An effective enforcement system of 5 inspectors will be created, in order to inspect electrical appliances, which are either imported or manufactured in Israel, and verify that they comply with the required energy efficiency levels.

9. Expected decrease in demand as a result of the scrapping programs (the replacement of old and inefficient appliances with new and efficient ones)

As aforesaid, the effect of the new regulation, as far as the self purchase of electrical appliances is concerned, does not apply to all the households. Due to the socio-economic status of the disadvantaged populations38, they cannot afford to buy new and efficient electrical appliances in a short period of time, if at all. Therefore, in order to include these populations in the energy efficiency process, the option to introduce regulated electrical appliance replacement programs will be examined.

As aforesaid in section 5 above, the number of households in which the incentive program will be examined, and which will be excluded from the regulation effect analysis, is calculated as follows: The number of disadvantaged population households that have the electrical appliance minus the number of households that will purchase a new appliance following the banning of an old one.

The following are the parameters that will be weighted in order to estimate the extent of efficiency, assuming that appliance replacement incentives are granted:

- The annual household energy savings as a result of using an efficient appliance.
- The duration of the expected replacement program – in accordance with the appliance's life span.
- Number of disadvantaged population households in which the electrical appliance exists, and which are not likely to purchase a new product.

It should be emphasized once again that the replacement incentive programs will not be examined for luxury products such as television sets, clothes dryers and dishwashers.

The effect of disadvantaged populations was not weighted in the forecasts of the Israel Electrical Corporation (as the regulation change does not affect the majority of these households, which cannot afford to buy electrical appliances). Therefore, the reduced consumption among disadvantaged populations will be weighted in full within the replacement programs (from a 'pre-regulations' consumption level to a consumption level that complies with the upgraded regulations). This, despite the fact that the present demand forecasts of the Israel Electrical Corporation (from mid 2009) internalize the effect of the change in Refrigeration and Air Conditioning Regulations;

[38] The scope of household of disadvantaged populations was correlated to the number of households receiving income assurance.

The following table displays the data required for examining the grant of replacement incentives:

Ovens	Washing machines	Air conditioners	Refrigerators	Electrical appliances data – replacement incentive programs
9	[40] 553	1,344	1,278	Annual household energy savings due to the use of an efficient appliance[39] (in kWh)
10	8	10	10	Replacement program duration (in years)
541	530	331	536	Number of low socio-economic households, in which the product exists and covered by the incentive programs (in thousands)

The following table displays the decrease in demands until 2020, due to the application of the replacement incentives (in millions of kWh):

2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	Cumulative energy savings since 2010
685	616	548	479	411	342	274	205	137	68	Refrigerators
400	356	311	267	222	178	133	89	44	0	Air conditioners
293	256	220	183	146	110	73	37	0	0	Washing machines
1,378	**1,228**	**1,079**	**929**	**780**	**630**	**481**	**331**	**181**	**68**	**Total decrease in demands due to the replacement programs (in millions of kWh)**

This decrease in demands is a result of the refrigerator replacement incentive program for disadvantaged populations which will begin in 2011, the provision of refrigerator replacement incentives which will begin in 2012, and the washing machine replacement effort which will begin in 2013.

The decrease in electricity purchase costs (capitalized)[41] among disadvantaged populations until 2020, as a result of the incentives granted for the replacement of electrical appliances into efficient ones, has a present value of about 2 billion NIS.

[39] weighted with regulation change.
[40] The use of hot water in washing machines is not included, in light of the fact that disadvantaged population households reside in old buildings, and do not purchase new apartments in which hot water for washing machines can be generated.
[41] Assuming a capitalization rate of 6%.

The following table sums up the expected saving in costs per electric appliance type until 2020 (in millions of NIS):

Capitalized saving by 2020 (in millions of NIS)	Electrical appliance type
1,086	Refrigerators
565	Air conditioners
364	Washing machines
8	Ovens

With such an extent of savings, it is advisable and economical to grant 50% government incentives for the replacement of electrical appliances[43]; i.e. the present value of the investment is significantly lower than the present value of the resulting financial saving flows.

However, the extent of the efficiency incentives and the rates of State subsidy will be derived from the present value of appliance replacement savings among disadvantaged populations, in relation to the present value of savings in other sectors or branches.

In accordance with the efficiency fund's allocations which are described in chapter K below, the following table displays the State participation in the replacement of refrigerators, air conditioners and washing machines among the entire households of disadvantaged populations. The total budget for State subsidies is approximately 450 million NIS until 2020 (capitalized).

Rate of State participation	Cost of average electric appliance (in NIS)[44]	Type of electrical appliance
25%	2,500	Refrigerators
25%	1,500	Air conditioners
25%	1,500	Washing machines
Not economical	2,000	Ovens

Conclusions:

The State offers 25% participation in the cost of refrigerators, air conditioners and washing machines (through the energy efficiency fund, or through other designated State budget sources). A total of about 450 million NIS (capitalized) will be given over a period of 10 years within the frame of the incentive program for disadvantaged populations. The State participation will make it possible to achieve an approximated 2 billion NIS decrease in electricity purchase costs (capitalized), even among populations that are generally much less likely to replace inefficient electricity products

[42] Based on data of the Israel Electrical Corporation – 2008 statistical report, average cost per kWh in the household sector;
[43] Except for oven replacement.
[44] Assuming the publication of a large scale government tender which promotes 'economics of scale'.
[45] Not including installation cost.

In order to make it easier for disadvantaged populations to face the required one-time expense of purchasing an efficient electrical appliance, several options should be evaluated. One of these options is to utilize electrical appliance replacement incentives that exist in programs of the Ministry of Welfare. Another option is to use the national insurance mechanisms in order to offer a generous installment plan, etc.

10. Light bulb efficiency replacement program in the household sector:

Economical light bulb replacement offers higher savings compared to costs. The replacement program, which will be applied on all households, is presented below.

The analysis is based on the following data:

- About 70% of Israel's households have a light bulb replacement potential (30% of the households are energy efficient).
- There are 5 bulbs per home; each bulb works 5 hours per day.
- Five 87.5 watt bulbs (an average figure, assuming an identical amount of 75 watt and 100 watt bulbs) are replaced by 16.5 watt bulbs (an average between 13 and 20 watt).
- The cost of one bulb, as a result of economics of scale, is 12.5 NIS. State participation covers 20% of the bulb's price.

The assessment reveals that annual energy efficiency per household sums up to about 650 kWh. Energy efficiency in 2010 is estimated at about 1 billion kWh, costing the household sector approximately 428 million NIS this year[46].

The plan is to introduce economical light bulbs in all households during the course of 2011.

The decrease in electricity purchase costs (capitalized) among household sector consumers by 2020 due to the replacement of economical light bulbs in all households, has a present value of about 3 billion NIS[47].

The cost of the economical light bulb replacement program in all households, on the other hand, is about 19.3 million NIS.

It is recommended to quickly implement this program, in light of the substantial gap between the reduced costs of electricity as a result of the introduction of economical light bulbs, and the costs of the bulb replacement incentive program.

In the meantime, efforts are continuously made to apply relevant regulations which will prohibit the import of inefficient light bulbs (60 watt and higher).

11. Public information program in the household sector:

We have the efficiency methods which were presented above, and which rely on **electrical-appliance-derived efficiency measures** for consumers, i.e. increased efficiency due to regulation changes and the provision of replacement incentives. Besides them, there is also another method of efficiency which relies on **a change in consumer behavior and in the way electrical appliances are used**, making it more rational and efficient.

According to present professional estimations, a 15% saving in consumption can be achieved due to the change in household consumer behavior along the years. However, our working assumption is conservative and relies on a mere 10% reduction in consumption as a result of the public information programs.

[46] Based on data of the Israel Electrical Corporation – 2008 statistical report, average cost per kWh in the household sector;
[47] Assuming the implementation of an initiated economical light bulb distribution plan during the course of 2011; hence, household replacement will be completed on average in the middle of 2011.

The main change in consumer behavior is expected to be more substantial during the first years following the introduction of the public information campaigns. As the years pass, the potential for change in consumption habits reduces. Therefore, our assumption relies on a 3% reduction in demands in 2011, and on a consistent 0.5% annual decrease in this rate until 2015 (in 2015, the annual decrease in demands due to the change in consumer behavior will be 1%).

Later on, between the years 2016-2020, additional public information campaigns will be required, in order to maintain public awareness regarding the importance of energy savings. However, it is assumed that these campaigns will not promote any additional decrease in demands beyond the said 10%.

The extent of efficiency (in millions of NIS) following the public information campaigns will rely on the decrease in consumption that will be prompted by the regulation changes and by the replacement incentive programs for disadvantaged populations. This will be calculated in section 11 below.

12. Summary of efficiency programs in the household sector:

The household sector efficiency programs which were reviewed above rely on regulation changes, consumer behavior changes as a result of public information campaigns, and the provision of electrical appliance replacement incentives for disadvantaged populations. These programs contribute substantially to the decrease in electricity demands.

The following table displays the expected decrease in demands until 2020 (in millions of kWh):

2020	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	
3,233	2,901	2,579	2,270	1,976	1,604	1,245	896	559	231	Regulation changes – 7 major electrical appliances, on operation and stand-by modes
1,378	1,228	1,079	929	780	630	481	331	181	68	Provision of replacement incentive for disadvantaged populations
1,407	1,360	1,314	1,269	1,227	1,185	1,145	1,106	1,069	516	Replacement to economical light bulbs
1,695	1,670	1,647	1,625	1,603	1,592	1,423	1,179	860	481	Public information campaigns
7,713	**7,160**	**6,618**	**6,094**	**5,585**	**5,011**	**4,293**	**3,513**	**2,669**	**1,297**	**Total decrease in demands in the household sector (in millions of kWh)**

The decrease in electricity purchase costs (capitalized)[48] among household sector consumers by 2020 due to the implementation of the efficiency programs, the public information programs and the regulation changes, has a present value of about 14.7 billion NIS.

Assuming that every 1 kWh emits 0.75 kg of CO_2, it is expected that Israel's economy will save in 2020 alone 5.8 million tons of CO_2, and the cumulative saving by 2020 will reach 37.5 million tons of CO_2.[49] Assuming a cost of 15 Euros per 1 ton of CO_2, **it is expected that Israel's economy will save about 560 million Euros, until 2020, as a result of increased household sector efficiency.**

48 Assuming a capitalization rate of 6%.
49 The reduction in greenhouse gas emissions is an additional result of energy savings, which is the program's main goal.

The anticipated reduction in household electricity demands by 2020 will be equivalent to the production capacity of a 1,600 megawatt power plant.

The cost of 1 installed kilowatt is estimated at approximately 1,250 dollars. Hence, the anticipated savings in the household sector alone will bring an approximated 2 billion dollar saving on the construction of an additional power plant, which would no longer be required.

****

References

[1] E. Bet Hazavdi, Drori A:State of Israel, Ministry of National infrastructures. National Energy Efficiency Program Reducing Electricity Consumption 2010 – 2020, July 2010.(can be download from: http://www.mni.gov.il/mni/en-US)

[2] Statistical report 2008: Israel Electrical Corporation (Hebrew), (can be download from http://www.iec.co.il/Static/WorkFolder/Investors/stat_rep_2008_he.pdf)

[3] Stat of Israel statistic report Israel's Central Bureau of Statistics: energy 2008 http://www.cbs.gov.il/reader/

[4] State of Israel. Energy Resources Regulation,. 1998, 2004, 2008, state of Israel. (Hebrew).

Overview of UNDP-GEF Energy Efficiency Project: Overcoming Barriers in Promoting Energy Efficiency in Nigeria

Etiosa Uyigue, Jason Yapp, Muyiwa Odele and Benoit Lebot

United Nations Development Programme (UNDP), Nigeria

Abstract
Nigeria, with a population of over 140 million people, only about 40% of these people have access to electricity. Electricity consumers suffer from frequent power outages which last for several hours. The power currently generated in Nigeria is inadequate and unstable, forcing industries, businesses and households to rely on diesel and petrol generators as primary or back-up source of electricity, which is expensive and a source of noise and air pollution. The government has focused on supply side management by generating electricity using gas powered thermal stations, which is a non-renewable source and will result in the emission of greenhouse gases (GHG). To address these problems, the United Nations Development Programme (UNDP) in partnership with the government of Nigeria commissioned a GEF funded project to improve the energy efficiency of a series of end-use equipment used in residential and public buildings in Nigeria. This entails the introduction of appropriate energy efficiency policies and measures and demand-side management programs. Another objective of the project is to strengthen the regulatory and institutional framework, develop stringent monitoring and enforcement mechanisms, establish internationally accredited testing laboratories, provide training to appliance and equipment professionals, and launch a public outreach campaign to promote energy efficiency in Nigeria. This paper identifies the barriers and risks to mainstreaming energy efficient in appliances in Nigeria. Opportunities to leverage carbon finance for the promotion of energy efficient appliances will be discussed. Lessons learnt will be used in shaping the regional policy to promote energy efficiency across the Econmic Community of West African States (ECOWAS) sub-region.

Key words: Nigeria, energy efficiency, electricity demand side management, carbon finance, UNDP, GEF

Introduction

Globally, about 60% of CO_2 emission comes from energy generation (Lebot, 2009) contributing significantly to global warming leading to climate change. One of the ways that have been identified to reduce the impacts of energy generation on the fragile environment and at the same time increase access to electricity is the development of energy efficiency projects and programmes. Moreover, energy efficiency will play a pivotal role in the mitigation of climate change as asserted in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC).

Energy efficiency has become the key driver of sustainable development in many economies in the world. Energy efficiency measures have the potential to promote economic development and can lead to job creation and saving of personal income. The efficient use of energy will help to reduce family energy bill. It will avoid the need to build more power stations, thus the money saved could be spent on other sectors of the economy and the energy saved will make it possible for more people will have access to energy.

For a population of over 140 million people in Nigeria, only about 40% of these people have access to electricity. Majority of the people having access to electricity leaves in the urban areas. In places where there is access to electricity, consumers suffer from frequent power outages which last for several hours. In a survey conducted in 2009 in three large cities in Nigeria – Abuja, Lagos and Benin City, out of the 150 respondents, over 80% of those interviewed do not get electricity supply for up to 24 hours a day

(CREDC, 2009). Majority of respondents get electricity from zero to about six hours a day. This is a likely reflection of the power supply scenario in all urban areas in Nigeria (Fig. 1).

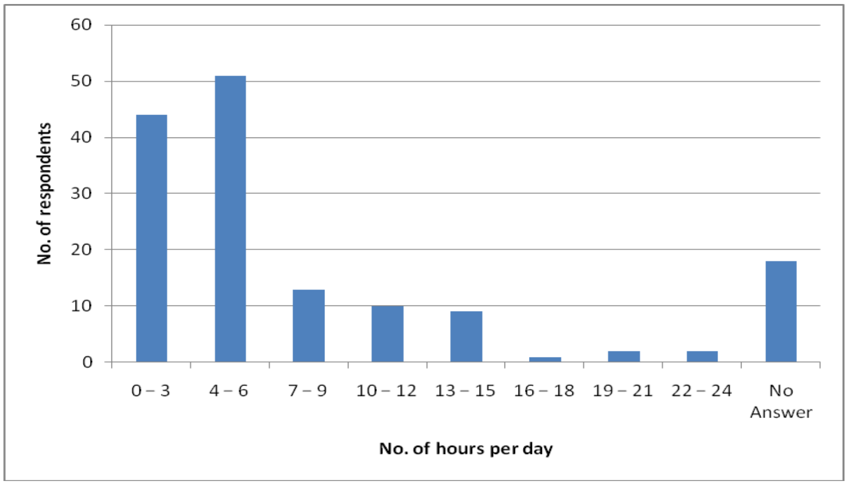


Fig. 1: The numbers of hour respondents get electricity per day

The power currently generated in Nigeria is inadequate and unstable, forcing a large portion of the industry, businesses and households to rely on diesel and petrol generators as primary or back-up source of electricity, which can be expensive and a source of noise and air pollutions. The National Electricity Regulatory Commission (NERC) estimated that Nigerians spend up to N769.4 billion (USD 89.5 million) annually in fueling generators. Of this amount, N540.9 billion (USD 69.2 million) was spent on diesel-powered generators, while N255.5 billion (USD 32.7 million) was spent on buying petrol for generators.

The Power Holding Company of Nigeria (PHCN), like numerous utility companies in Africa, is facing difficulties to keep up with electricity demand. There are nine electricity generating stations in Nigeria. Three of these stations are hydro based while six are thermal based and they are all owned by the government under the PHCN. The total installed capacity of these power generating facilities is 6,000 MW. Hydro electric dams are expected to contribute 40% of this energy while gas-powered thermal stations are to contribute 60%. However, for many reasons ranging from shortage of gas supply to lack of maintenance, these stations are performing far below the installed capacity. The total energy currently generated in Nigeria is about 5,000 MW. Out of this, 65% is consumed by the residential sector, 20% in the commercial sector and 10% in the industrial sector while the remaining 5% is exported to Niger, Togo and Benin Republic.

The plan of the Federal Government of Nigeria is to generate electricity using gas powered thermal stations, which is non-renewable source and will result in the emission of GHGs. With Nigeria having one of the largest gas reserve in the world and a large population, the high demand for electricity will force the government to invest and commission several more thermal stations to meet up with demand. The poor power production and supply is further exacerbated by high distribution losses due to inefficient distribution system. Since the utility companies do not have enough energy to meet the needs of everybody at the same time, energy supply is alternated to different areas.

In the mist of these crises in the energy sector in Nigeria, the United Nations Development Programme (UNDP) is partnering with the government of Nigeria to seek support from the Global Environment Facility (GEF) to develop a program to promote energy efficiency for a series of end-use appliance used in the residential and public sectors. The objectives of this paper are to enumerate the four basic components of the UNDP GEF project and to identify barriers and risks for the mainstreaming of energy efficient appliances in Nigeria. Opportunities to leverage carbon finance for the promotion of energy efficient appliances will be discussed. Lessons learnt from the project will be used in shaping the regional policy to promote energy efficiency across the ECOWAS sub-region.

Barriers to Developing Energy Efficiency Programmes

There are multitudes of barriers that have been identified that can hinder the energy efficiency in Nigeria. These barriers could also be applicable to other countries in the West African sub-region as the socio-economic environments are not very different.

Policy Barrier

The lack of clear policy framework and regulations to introduce and mandate legal energy efficiency requirements is a key barrier to the development of energy efficiency in Nigeria. Policy and legislation are two elements that can help to change human behavior as well as sending the right signals and drivers to investors for market transformation. The absence of energy efficiency policy in Nigeria is due to the lack of awareness and understanding among Nigerian policy makers and other stakeholders of the potential for reducing energy demand through energy efficiency at the end-use sector. Rather than just focusing solely on increasing supply side management, efforts to promote energy efficiency measures will help to bring economic, social and environmental benefits.

Legislative Barrier

There is no legislation in Nigeria that promotes end-use energy efficiency. The Standard Organization of Nigeria (SON) does not have standards for energy efficiency (EE) of end-use appliances. From consultation with stakeholders, popular opinions from experienced policy and law makers see the great importance of passing new energy efficiency legislation in order to have stronger mandate to promote energy efficiency. In the legislative arm of government, there is lack of capacity to develop EE legislations. The legislative system therefore does contemplate at the present the development of EE legal framework, chiefly due to absence of information, knowledge and culture to understand the need for energy efficiency action. Thus the Legislative Arm of Government is unable to use both the budget and oversight tool to ensure effective regulation and guidance of the process of effective implementation of energy efficiency policy.

Information Barrier

The concept of energy efficiency is poorly understood and developed in Nigeria even among policy makers and legislators. This is a very important barrier that the UNDP/GEF project will address. Awareness creation will go a long way to help people understand the concept and change their behavior. Little information is available at the government level on the potential impact and cost effectiveness of energy efficiency regulation. End users lack information about the availability of energy efficient equipments and the cost effectiveness of investing in efficient appliances. This poor perception of energy efficiency measures is further exacerbated by the proliferation of expensive and inferior counterfeit imported appliance with no standards or labels.

Technical Barrier

Inadequately trained personnel and professionals is another factor inhibiting the development of energy efficiency in Nigeria. Out of the 150 respondents interviewed in the study conducted by Community Research and Development Centre(CREDC) in 2009, 77% of them said that no member of their organizations has been trained on energy management. Nigeria as a country lacks adequate energy efficiency experts that will drive the development of energy efficiency policy and projects/programmes. The agency, the Standard Organization of Nigeria that is responsible for developing and enforcing standards in Nigeria do not have the technical capacity to develop and enforce energy efficiency standards.

Research and Development Barrier

In Nigeria, there is lack of sufficient organized research materials and data that will guide the development of policy and legislation that will strengthen the efficient use of energy. Also there is lack of material to conduct training on energy efficiency. All these point to the poor development of the concept in Nigeria. The absence of coordinated and organized research materials and data is hampering the design and development of sound energy efficiency policy and legislation. The only organized research materials found was the one published by the CREDC in 2009.

Cost Barrier

Price is a very strong economic factor influencing the demand for goods and services. A total of 51% of respondent from a survey conducted by CREDC agreed that they consider the price of appliance before they purchase one. In many cases, the prices of less efficient appliances are low compared to the more efficient ones. Many stakeholders in Nigeria complained that the prices of energy efficient bulbs are on the high side compared to incandescent bulbs. The desire to minimize initial cost force many consumers to purchase cheap and inefficient appliances. For example, the cost of energy saving bulbs in the Nigerian market is about N800 ($5.33) and above compared to an incandescent bulb which cost about N40 ($0.27). Worse still, some of these expensive 'so called energy efficient bulbs' are counterfeits which are being dumped into Nigeria and they do not last as long Many consumers will prefer to go for the cheaper ones (CREDC, 2009).

Income Barrier

About 70% of Nigerians live below the poverty line of USD$2 per day. Many are not able to afford the cost of energy efficient appliances which are sometime more expensive than the less efficient ones. Many Nigerian cannot afford energy saving bulbs. This is the reason why many Nigerians go for secondhand goods. The proliferation of imported secondhand appliances may hinder the use of efficient appliances. The reason is that these secondhand products are cheaper compared to the new ones and easily available; the new and efficient ones may be unable to compete with them in the market. The Nigerian market is flooded with all kinds of secondhand appliances.

Institutional Barrier

There is lack of capacity in government ministries and institutions on how to specifically proceed to implement and enforce energy efficiency regulations, and how to develop and support energy efficiency schemes such as standards, codes, certification and labels in order to speed up the market transformation process. For instance, the Standard Organization of Nigeria does not have any standards for EE.

Market Barrier

Local medium size manufacturers lack capacity to develop and market more efficient appliance and are uncertain about the market demand of high efficiency models. Retail staff and commercial staff do not pay attention to and do not know how to market energy efficient appliances. Hence retailers do not offer a sufficient range of efficient equipment because of the lack of demand for this type of appliance. The uncertainty on availability of energy efficiency products is another barrier that should be addressed.

The proliferation of substandard products is another market barrier that needs to be addressed. During consultations with stakeholder, it was revealed that some Nigerian businessmen go to countries like China and India to buy substandard products and bring them into the Nigerian market. Stakeholder complained that energy efficiency bulbs in the market do not last long, and thus people do not have faith in the products. Many of them will prefer to continue using the incandescent bulbs instead of buying energy efficiency bulb every now and then. This is an important barrier that UNDP/GEF project will address, to build trust and faith in Nigerians to use energy efficiency bulbs and other appliances.

Governance Barrier

The problems facing the energy sector in Nigeria are partly systemic. Stakeholders have identified corruption in public offices as a potential barrier to the development of energy efficiency in Nigeria. This implies that a systemic problem will require systemic solution. The government has taken a giant step to address the problem of corruption in Nigeria by setting up two bodies, the Independent Corrupt Practices and other Related Offences Commission and Economic and Financial Crime Commission (EFCC) to combat corruption and other financial crimes.

Funding Barrier

Funding from government in the energy sector has concentrated on generation and distribution and little or none is allocated for the efficient use of energy. Again, many government agencies and programs especially energy efficiency projects are poorly funded because neither the executive nor the legislative arm of government has been adequately briefed on the benefits of energy efficiency programs.

Behavioral Barrier

Wasteful attitude and habits on energy use which is rampart in Nigeria is a barrier that the UNDP/GEF project will overcome. A lot of energy is wasted in Nigeria because households, public and private offices and industries use more energy than is actually necessary to fulfill their needs. The reason is that many Nigerians exhibit unwholesome practices that lead to energy wastage. Some of these energy wasteful behaviors were enumerated by the study conducted by CREDC in 2009. For example, it was revealed that many Nigerians do not turn off their outdoor lighting during the day. This is particularly very common in commercial and residential areas in many major cities in Nigeria. Even in public institutions such as universities, government ministries were also found to have their outdoor lighting switched on during the day. Often this is exacerbated by the frequent outages.

Technological Barrier

Sources (mainly importers of light bulbs) from the Lagos Chamber of Commerce have indicated that there is no manufacturing facility of energy efficiency light bulbs in Nigeria. This suggests that all the light bulbs are imported. Furthermore consumers complain of inferior and sub-standard quality of the energy efficiency bulbs, which often leads to malfunction, many times exacerbated by fluctuating voltage. There is a clear need for the consistent supply of competitive, high quality, affordable and reliable energy efficient bulbs in order to encourage their adoption and acceptance.

Enforcement barriers

Weak enforcement of national laws and regulations is another important barrier to the development of energy efficiency in Nigeria. The Standards Organization of Nigeria has recently introduced a third-party certification program for imported goods to combat the problem of substandard products, especially generators, which are flooding the market from Asia. The Consumer Production Council (CPC) has responsibility for enforcing consumer laws, but it has limited resources and does not have regional offices that would allow it to work more closely with local distributors and consumer protection groups to enforce regulations such as energy appliance labeling. There are reports that widespread smuggling is militating against government ban on the importation of used appliances. Lessons learnt from the successful banning of the chloro-flouro carbon (CFC) based appliances (e.g. refrigerators) by the National Ozone Unit in partnership with the Custom Department will be heavily utilized here to avoid any pitfalls.

Competitive barriers

Smaller domestic manufacturers worry that they may not have the financial or technical capabilities to compete with larger, more established manufacturers that have established partnerships with international consortiums and can benefit from their know-how. Furthermore, unless the government can stop the dumping of substandard products from Asia, domestic manufacturers may feel penalized if they must compete against imported products that do fail to follow the necessary labeling regulations.

UNDP/GEF Strategies to Overcoming Energy Efficiency Barriers

In 2009, the GEF approved a grant for UNDP to design a project to promote energy efficiency in residential and public sector. The overall objective of the project is to promote energy efficiency for a series of end-use equipment (refrigeration appliances, air conditioners, lighting, electric motors and fans, heating appliances etc) used in residential and public buildings (schools, hotels, offices) in Nigeria through the introduction of appropriate energy efficiency policies and measures (such as Standards and Labels) and demand-side management programs. Another objective of the project is to strengthen the regulatory and institutional framework, develop monitoring and enforcement mechanisms, establish testing laboratories, provide training to appliance and equipment professionals, and launch a public outreach campaign to promote energy efficiency in Nigeria. The opportunities to leverage carbon finance as programmatic carbon project for the mainstreaming of energy efficient appliances for overcoming the technical, regulatory and financial barriers will be explored. The various components of the project are enumerated below:

Policy and Legislative

The project will assist the government of Nigeria to put in place comprehensive energy efficiency policy and legislation. This is to establish an enabling regulatory and institutional framework for the development of end-use energy efficiency codes, minimum energy performance standards, standard labels & certification. This will help to reduce national carbon emissions from the adoption of more energy efficient appliances in the residential and public sector. For this component, technical assistance and capacity building will be provided to the government so it can proceed with standard and label implementation. This component also entails the support for the design of legal framework and the writing of the first set of regulations.

Establishment of Testing Centre

During the project, there will be established an independent internationally accredited testing centre to test for the efficiency of end-use appliance. The testing centre is expected to be beneficial to other ECOWAS States. This component will provide the relevant government agencies and at least one selected laboratory with support for the design of enforcement procedures and for the testing of appliances. The enforcement procedures will cover the manufacturers, importers and retailers and will ensure that all market actors are informed and are following the new regulation.

Training, Capacity Building and Awareness Creation

This component is designed to enhance the capacity of all relevant stakeholders at the national level of the concept, nature and potential of energy efficiency and train relevant professionals and carry out public outreach. In this component, national professionals are trained in energy efficiency program monitoring and evaluation study design, methods, technologies and procedures. The project will assess the current situation of energy demand in Nigeria and will progressively develop a good understanding of the end-use electricity demand. During the project, the Project Team will carry out end-use metering campaign, collect field data, organize market analysis, etc. This will help to set sound baseline analysis prior the transformation of the markets.

Pilot Project to Install CFLs

Under this component, one million compact fluorescent lamps (CFLs) will be distributed in residential and public buildings in Nigeria. This pilot will quantify the economic, social and environmental benefits of replacing old incandescent bulbs with CFLs. This outcome will address gaps on the influence of income level on consumer behavior change. It will focus on demonstration project, development of fiscal and market based financial tools (to leverage carbon finance as programmatic carbon project) for incentivizing behavior change towards energy efficiency appliances and design and costing of an incandescent bulb recycling facility for subsequent investment and commissioning. This component will also look into the safe disposal of old incandescent and CFLs products.

Lessons Learnt

So far on the implementation of this project, the Project Team adopted the bottom-top approach. The usual style where policies are developed in the offices of government officials without due consultation with the stakeholders has been a major hindrance in the implementation of policy. Many of these policies are made and are never implemented because they lack public acceptance and project ownership. The project is aware of this and thus adopted the bottom-top approach. Several consultation meetings were held since the commencement of the project to seek the opinion of stakeholders and their inputs into the project. This will give all stakeholders a sense of ownership of the project. In this way enforcement of policy will become very easy and as such will be driven by all.

Worthy of mentioning is consultation meeting with the Electrical Dealers Association of Nigeria (EDAN), major distributors and retailers of electrical appliances. After several consultation meetings with EDAN, the group promised to begin the importation of energy saving bulbs. The Project Team; through several meeting with the Council members of EDAN convince them on the importance of EE to the country. Thus before policy are made through official channels, stakeholder are already willing to carry out the policy. This is a demonstration of the power of consultation with stakeholders when developing any policy. Enhancing the capacity all stakeholders and proper consultation are critical for the success of EE project.

The Need for Regional Coordination to Promote Energy Efficiency

The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) was launched in November 2009 and is mandated to promote regional energy efficiency policies. ECREEE is well positioned to become an ideal platform to scale up the Ghana and Nigeria energy efficiency standard & label programme to the entire ECOWAS region. The project team has established strong alliance with the leadership of ECREEE. Countries in the region can benefit from the testing facilities that will be set up in Nigeria. The cost of building a standard testing centre is quite high and many governments in Region may not have the quantum of money to embark on such project. Hence, there is need for countries in the region to cooperate in the course of promoting energy efficiency.

A strong regional coordination will complement the goal set by ECOWAS to promote energy efficiency policies and practices in the region. In the ECOWAS Energy Protocol enacted 21 January, 2003 in Dakar, Senegal, in Article 43, ECOWAS Member States agreed to co-operate and, as appropriate, assist each other in developing and implementing energy efficiency policies, laws and regulations. The member state agreed to establish energy efficiency policies and appropriate legal and regulatory frameworks. Institutions in the ECOWAS member states mandated to promote energy efficiency can learn project in Nigeria to adopt the bottom-top approach in developing energy efficiency policy.

Conclusions

Within the region, Ghana has recorded promising success in the area of energy efficiency. The Ghana Ministry of Energy in August 2007 launched the National Compact Fluorescent Lamps (CFLs) exchange programme. The Ghanaian government had imported six million CFLs for distribution free of charge to all households in the country in exchange for incandescent bulbs. This was an emergency policy intervention measure to reduce peak electricity supply in order to resolve the power crisis, as a result of low rainfall which had affected hydro-electricity supply. Today, electricity is relative stable in Ghana compared to Nigeria and other countries in the region.

With Nigeria accounting for 25% of the population of sub-Saharan Africa, UNDP GEF energy efficiency project legislative package will have a significant impact on addressing the inevitable growth of electricity consumption in the region while contributing to greenhouse gas reduction. Nigeria's greenhouse gas emission is the highest in Africa, contributing 3% of global emission while the whole of Africa contributes 4% of GHGs emission. There is need to put in place strong mechanism for regional cooperation to promote energy efficiency across the ECOWAS region. This will help to achieve the agenda set by ECOWAS Member states as stipulated in the ECOWAS Energy Protocol.

There is need to network with all the relevant agencies and stakeholders within the region to build a strong coalition that will influence national and regional policy. The designed energy efficiency policy and legislations for the ECOWAS region can help to enhance the implementation of these national policies and legislation among the member states. We advocate a platform to organize regular programmes where stakeholders can meet and further strategize on ways to achieve better result and appraise energy efficiency activities within the member states and explore innovative market based mechanism for monetization of the environmental services into carbon assets as regional programmatic carbon project for the scaling up of energy efficient appliances in overcoming the technical, regulatory and financial risks.

References

Community Research and Development Centre. *Energy Efficiency Survey in Nigeria: A Guide for Developing Policy and Legislation.* A publication of the Community Research and Development Centre (CREDC). 2009. Can be downloaded in www.credcentre.org

IPCC. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Lebot, B. *Energy Efficiency and Market Transformation: A Short Overview of Best Practices*. A paper presented during the Inception Workshop of the UNDP-GEF Project to Promote Energy Efficiency in Residential and Public Building in Nigeria, 14th July 2009.

International Rivers. *Energy Efficiency: The Greenest Electricity Source*. Publication of the International Rivers. 2009). Can be downloaded in www.internationalrivers.org

International benchmarking: supplying the information for product policy makers

Stuart Jeffcott, Davide Minotti

Abstract

In the development of effective product policy, the critical element for decision makers is the availability of comprehensive, independent information. Accessible, reliable information on the performance of products and the policies that are designed to address that level of performance is often scarce within a particular market, and rarer still if the policy maker is seeking comparisons on an international level. Furthermore, even when resources are available to investigate the market prior to any major policy initiative, policy makers often have no information with which to decide the most appropriate places to target these resources, which can lead to fruitless investigations.

The IEA's 4E Mapping and Benchmarking Annex aims to fill the gap by providing policy makers with:

- time series data on the comparative performance of specific product sectors between trading blocks from around the globe
- analysis of the associated policy impacts that have lead to the varying performance levels.

This paper will provide an overview of outcomes for the first products mapped and benchmarked by the Annex (Domestic Cold Appliances, TVs, Air Conditioning). It will detail:

- some of the important lessons on data collection and processing
- policy recommendations on each product reviewed

Also included will be recommendations for how limited adjustments to national data acquisition will lead to significant improvements in policy making with the additional benefit of improvements in ongoing monitoring and evaluation of those policies.

Introduction

Appliances account for a large share of electricity consumption. Therefore product efficiency policy is an important part of energy policy in order to reduce CO_2 emissions, increase security of supply and fight energy poverty. In the development of effective product efficiency policy, a critical element for policy makers is comprehensive data over time on energy consumption and energy related characteristics of products. Since many products are traded world wide, policy makers and other stakeholders could benefit from data outside their country.

Energy performance maps have been produced for some products within specific countries, e.g. for refrigerator-freezers in the US [1]. Benchmarks of product performance are rare, although benchmarks of policies are more common, e.g. for electric motors [2]. There are also some examples of benchmarks for the most efficient products within regions, e.g. Top Ten Best of Europe [3] and an Asia-Pacific study on Air-Conditioners [4]. However, easily accessible, reliable information on the energy performance over time is scarce and rarer still is data on comparisons on an international level. Therefore countries[1] participating in the IEA 4E (Efficient Electrical End-use Equipment) Implementing Agreement established the Mapping & Benchmarking Annex in 2008. This Annex aims to provide policy makers with a single source knowledge base on product performance and associated policy tools employed by economies across the world, thus enabling more informed policy making at the national and regional levels.

In this paper we will first describe the processes employed to enable Mapping & Benchmarking and the benefits from the Mapping & Benchmarking approach for the countries participating in this 4E Annex. In the second section we will provide some of the results and policy recommendations for the first three product groups analysed by the Annex: domestic cold appliances, televisions, and air conditioners. The paper concludes with lessons learned regarding data collection and processing and recommendations for national data acquisition in future.

[1] Currently: Australia, Austria, Canada, Denmark, France, Japan, Korea, the Netherlands, South Africa, Switzerland, UK and USA.

What is Mapping & Benchmarking?

Introduction; definitions

Mapping is the process of collecting data on energy consumption and energy related aspects of a single product or category of products over a number of years to show the development over time of energy consumption, energy efficiency and other energy related aspects of that product for a country or region[2]. This process results in one or more 'maps'.

Mapping can be applied to different aspects/levels: the average stock of products in a country, the best products that are available on the market or best not available technology[3]. Regarding the products that are available on the market, a further differentiation is useful between performance levels achieved by the least efficient products, (sales weighted and/or product weighted) average, and performance achieved by the most efficient available products[4].

Benchmarking is the process of analysing comparable data on energy consumption and energy related aspects of a product or category of products across various countries or regions in order to compare product performance, analyse variations and show best practices. The results of this process are firstly data sets that can be fairly compared with each other, and secondly benchmarks on the various energy performance aspects to show how average, best and worst performance levels (for example) compare between countries.

Maps provide national policy makers with comprehensive information on the energy performance of a product locally, so that they can understand the trend and identify the range of efficiencies within the market. Benchmarks make the data between countries comparable, so that best practices can be shared and potential for further improvement of energy efficiency levels is highlighted. Benchmarks furthermore allow policy makers to spot "best and worst in class": the most and least efficient models of a certain product (subcategory), e.g. upright freezers. If the least efficient products in country A are more efficient than in country B, this might be a signal to strengthen minimum efficiency standards in country B. However the primary focus of benchmarking is on benchmarking facts, i.e. efficiency data of the market and stock over time.

Process of Mapping & Benchmarking

Mapping & Benchmarking is a collaborative process within the 4E Mapping & Benchmarking Annex, involving the direct participation of government officials and/or their experts in the work of the Annex. All participants are engaged and agree on the important decisions, regarding product definitions and normalisation. Furthermore, prior to publication of the final maps and benchmarks all participants have to agree on the map of their data and the benchmark based on that map.

Product selection

Participating countries in the Mapping & Benchmarking Annex selected the following product categories to be addressed first: domestic cold appliances, televisions, domestic laundry appliances, domestic air conditioners, laptop computers, water heaters, lighting and laundry dryers.

Criteria for the selection were significant level of electricity consumption and/or contribution to peak load and the likelihood of availability of sources of information. The selected products consume on average in the EU 36 % of household electricity consumption [5].

A number of steps can be distinguished in the Mapping & Benchmarking process [6]. However, before mapping and benchmarking can start, products or at least product categories need to be defined.

Product definition and definition of required data

For a given product, the first step in the process is the product definition. The product definition should be such that it is clear which data sources can be used; the product definition should be broad enough to encompass product variants in different parts of the world. Mainly this means that the product definition in principle will be based on functionality. However, a general product definition – e.g. a television is a product of which the main function is to receive and to process a broadcast signal and to display the

[2] A relevant region is the EU, because product efficiency policy to a large extent is set by the European Commission. In the maps and benchmarks the EU is treated as a "country".
[3] BNAT: best not available technology. Aspirational performance levels that are likely from known near-future technologies. Because product development of most products is world wide, it is not likely that this data is available per country.
[4] BAT: best available technology

results by means of a screen while reproducing the accompanying sound – might be too general for product policy. Therefore products may need to be sub-categorized by:

- Functionality (beyond the main function)
- Technology
- Size, capacity

In the 4E Annex a product sub-category selection process has been developed. In the first step a product sub-category matrix definition is established. This matrix consists of the product parameters and the values for these parameters; generally the combinations of the values for the parameters result in a very large number of possible product sub categories.

In the second step the number of sub-categories is often reduced based on functionality. The final steps in rationalising the overall product matrix is the removal of sub-categories where testing methodologies have normalised for performance variations, and the removal of sub-categories with low market share across the majority of participating countries.

Before the final selection of product sub-categories is made, an assessment of available data is carried out because, in order to produce meaningful maps and benchmarks, data must be available on the sub-category level.

Regarding the required data, energy consumption and energy efficiency are central. In general energy efficiency is the energy consumption of the product per functional unit. This requires definition of a functional unit, e.g. unit volume of cool storage space, or kg wash cleaned. In some cases where a strict energy efficiency metric is not appropriate, an alternative such as the energy consumption per product sub-category may be used.

Energy consumption will also need further qualification, e.g. energy consumption per day or year (cold appliances, air conditioners, televisions) or per cycle (washing machines, dishwashers, dryers). Required data can typically be categorized as follows:

- New product data on energy consumption and energy related performance aspects, preferably sales weighted (market information).
- New product data on other product aspects that affect energy performance (e.g. screen size)
- New product data that is used for product normalisation (e.g. climate class used for testing).
- Test methodologies used and their relationship to known international standards.
- Stock information: efficiency, total number in stock.
- Data on policies directly influencing the energy efficiency of the product.

Based on experience a two stage process has evolved where a draft definition and data requirement is created, followed by an investigation into data availability within participating countries. A re-analysis is then undertaken to establish how the product definition can be revised in line with data availability while still maintaining sufficient integrity in the following benchmarking to ensure potential results are useful and reliable. In the case of water heaters, this has led to the temporary suspension of the product definition process as the characterisation of products and the test methods used at the local level (and consequently available data) are such that the sub-categorisation and ultimate benchmarking is unlikely to produce meaningful results.

Data collection and processing

The required data is sourced per product sub-category and country. To increase the ease of data processing and analysis, and to increase the reliability of the resulting output, original data sets are preferred, i.e. data sets with raw data per model. Other data sources used include analysis reports based on original data sets, commercial data (e.g. GfK) or reports with meta-analysis.

The quality of the data can vary. The quality of the data determines the quality of the conclusions that can be drawn from the data.[5] As would be expected of data from multiple sources, definitions of data quality can be challenging. In particular, understanding the composition of the data set and its representativeness of the market can be challenging.

---

[5] 5 Three quality levels are used to give an indication of how robust a dataset or benchmark is. They are: robust; indicative and illustrative.

While product level data is preferred, much data is supplied at the market average level. This introduces a degree of uncertainty as any data manipulation that follows as part of the mapping or benchmarking process will inevitable increase the degree of error in the final results

Producing maps

The collected and processed data now allows for producing maps. It is useful to have several maps per country to display different aspects. In the next section we will show some examples of maps produced by the Annex.

Normalisation; analysis of test methods

In comparing product performance across countries and regions, some allowance has to be made for variations that are due to the way in which data on energy performance was measured in each country. These include:

- Variation due to product performance aspects (e.g. climate class (temperature/humidity) at which the product is designed to operate);
- Variation due to environmental (test) conditions, e.g. different supply voltages or water inlet temperatures;
- Variation due to the use of different test methodologies between countries but also over time (changes/developments in test methodologies).

As a result of these variations the data from different countries and/or from different years can not be directly compared in all cases. Therefore normalisation of data is necessary.

Normalisation is done by applying conversions factors, based on known and widely accepted factors, preferably evidence based. Where conversion factors were not available, expert opinion (including experts from industry) has been sought to propose factors. If no reliable conversion factors could be found data has been reported separately, i.e. benchmarking all participating countries against each other was not possible in a reasonably fair way for that aspect.

Producing benchmarks

The normalised data is used to produce benchmarks. In the next section we will show some examples of benchmarks produced by the Annex.

The quality of the benchmarks is determined by the quality of the underlying data sets and the robustness of the normalisation. As for mapping this has consequences for the quality of the conclusions that can be drawn.

Benefits from the Mapping & Benchmarking approach

The Mapping & Benchmarking approach described in the foregoing section offers a structured framework for countries to collect and present efficiency data for products that are relevant for their product efficiency policy. The benefits of this approach fall in two categories: the benefits of Mapping & Benchmarking *as such*, and the benefits of a *collaborative* approach.

Regarding the first category it is clear that comprehensive information on the energy performance of products in the market is beneficial both to the evaluation and review of existing policies and to the design of new policies. For example, the EU's ecodesign preparatory process of implementing measures asks for such data (see [7] and [8]). Not only data on their "own" national market is useful, but also comparative information on the international level can bring energy efficiency forward[6]. Within the Mapping & Benchmarking Annex these benefits are not only for participating governments, but also for a wider audience, e.g. industry, since in the end the (main) Mapping & Benchmarking results are placed on a publicly accessible website (www.mappingandbenchmarking,iea-4E.org). This enables industry and other stakeholders, e.g. NGOs, to discuss policies on the same data basis.

[6] For example see the discussion on the ecodesign requirements for electric motors where the Commission invited US industry experts to the Consultation Forum to give a presentation on development of minimum efficiency standards.

The benefits of a *collaborative* approach are burden sharing and improved learning. Collaboration in the Annex reduces the cost per country[7] and improves the quality. Various datasets used in the Mapping & Benchmarking process are only available because the government officials participate in the process. Furthermore, the structured, collaborative approach stimulates improved learning, e.g. awareness of key issues and ownership of results, through regular presentations and discussions of the (draft) results. Through input from experts from all over the world more input is provided to the process than when done by a single country on its own and decisions on e.g. conversion factors can be better substantiated. This wide collaboration also has a knock on benefit of a larger pool of policy makers/experts have a greater understanding of the challenges of non-harmonised test methods, product categorisation and non-aligned data capture practises and hence increases the motivation to align such differences in the future.

The collaborative approach also has some disadvantages, mainly being the loss of flexibility of a single country to decide on the products to be analysed. Countries may have a different priority for some product based on their specific situation that is not matched by the average priority of the group.

The next section provides results and policy recommendations for the first three benchmarked products.

Cold appliances - Results and Recommendations

Product definition

For cold appliances, refrigerator-freezer combinations and freezer only units have been selected as relevant product categories for policy makers in the participating countries as they are the dominant products in almost all countries (ie stand alone refrigerators were not taken into account). The product categories have been considered based on functionality, i.e. they perform the same basic function of cooling or freezing in the relevant compartment contents.

The following metrics have been defined:

- Unit Energy Consumption in kWh/year (total consumption, not corrected for volume or other parameters).
- Unit Energy Efficiency in kWh/litre/year (corrected for adjusted volume of individual compartments, no correction for other parameters).

Data processing and normalisation

Cold appliances are amongst the few products that have been subject to regulations (minimum efficiency standards and labels) for more than a decade in many economies. For most of the countries time series data of 10 years or more are available, either through government databases (Australia, Austria, Denmark, Canada, Korea, US, and China), industry sources (Switzerland) or commercial sources (UK and EU).

For normalisation the following correction factors have been applied for: the different proportions of fresh and frozen compartments; the presence of icemakers; the allocation of the declare energy consumption to fresh and frozen compartments and adjustment for difference between internal and external temperatures according to various test methodologies. Normalisation was based on conversion of energy consumption to the EU differential test temperatures[8].

Results and observations

Data on refrigerator/freezer combinations only are presented (for reasons of space – data on the freezer only units are in [9]) in figures 1 and 2. These benchmarks show that both annual energy consumption (kWh/year) and efficiency (kWh/adj. litre/year) are improving over time. However, comparison of the figures also shows that efficiency is not always a good indicator of annual consumption: whereas in 2008 the efficiency of combined refrigerator-freezers in the EU is the worst, the annual consumption is amongst the lowest.

[7] In principle the cost for Mapping&Benchmarking for 1 country is more or less the same as the cost for all countries, assuming that the benchmark is based on data from all countries.

[8] alternative correction factors have been proposed for the normalisation of testing temperatures between countries/regions. While the vast majority of the analysis presented is applicable to both the conversion factors used and the alternative conversion factors, the alternative correction factors lead to results that differ from those presented in this paper

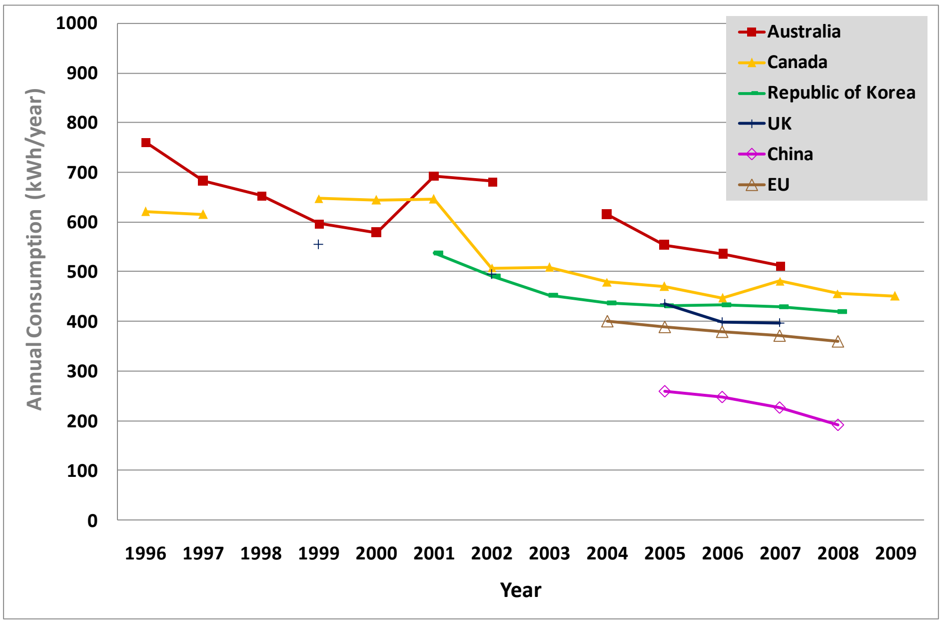


Figure 1. Indicative Normalised New Product Weighted Energy Consumption (kWh/year) [9] p. 6

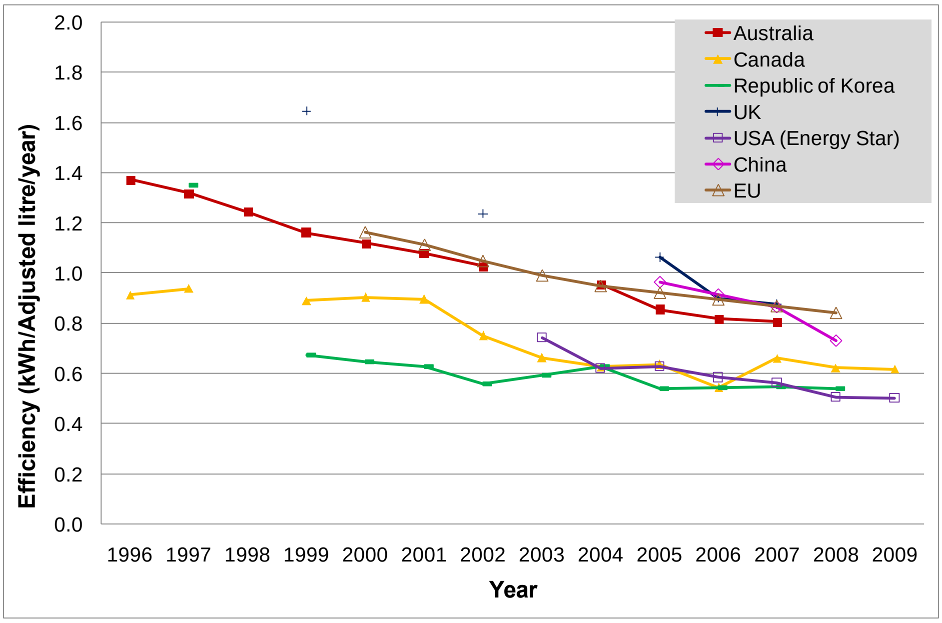


Figure 2. Illustrative Normalised Efficiency of New Products (product weighted, kWh/yr/adjusted volume) [9] p.41

Other key observations include:

- The markets where mandatory labelling and/or MEPS were introduced earlier and/or are revised regularly (Canada, Korea and the USA) tend to be those markets with the better performing products. However, as similar measures have been introduced in the remaining countries (Australia and the UK), efficiencies are rapidly improving and are beginning to approach the better performers (Australia's efficiencies are approaching the "norm" more quickly, possibly because their policies appear to be reviewed more regularly).
- The explosive growth in ownership levels in China is more than outweighing any overall energy/efficiency gains made elsewhere (despite rapid improvement in the performance of Chinese products).For refrigerator/freezer combination units in 2006, Chinese consumption was already at 60% of the combined consumption of Canada, Denmark, France, Korea and the UK. However, since that point, Chinese consumption has risen by over 35% and is likely to have surpassed the combined consumption of these nations. However, Chinese ownership levels are

still less than one appliance in every 4 households so consumption will almost certainly continue to grow rapidly and for an extended period even with strong policy intervention.

Policy recommendations

Based on these findings policy recommendations include:

- The combination of MEPS and Mandatory Labelling appear to have maximum market impact provided they are reviewed frequently.
  In general, product efficiency is inherently improved as volumes increase. Thus, the use of energy efficiency as the sole metric for policy development and evaluation may be misleading and may actually lead to perverse outcomes if products are increased in volume (and potentially consumption) simply to improve apparent efficiency. As the control of volume growth is likely not to be possible, policy makers should consider the development of policy based on consumption caps (and consequently efficiency caps).
- Given the explosive growth in product ownership in China, and the huge ongoing potential for continued growth before the market begins to approach saturation, any technical or policy support that can be offered in managing this growth in demand would yield very high returns. Therefore, policy makers outside of China may wish to consider the value of redirecting some of their resources which are currently focusing on their domestic markets towards supporting the China government in actions being undertaken to manage demand.

Televisions - Results and Recommendations

Product definition

For the Mapping & Benchmarking process a television has been defined as 'a commercially available and mains electricity powered product consisting of a display and one or more tuner(s)/receiver(s) combined in a single housing. It is designed to receive, decode and display audiovisual signals and reproduce sound from analogue sources and/or digital sources that are decoded directly broadcast via satellite, cable or antenna signals. In the case of digital sources, decoding may be via any external adaptor or receiver' ([10], p. 1).

Excluded were combination products, e.g. products with an integrated DVD player/recorder or hard drive; televisions with screen sizes under 28 cm and television monitors and computer displays.

For the analysis data was collected on power consumption in on-mode and standby mode, screen size and aspect ratio (to calculate screen area) and screen technology.

Data processing and normalisation

Data was obtained from several sources: GfK (EU, Austria, France), government databases (Korea, UK), industry organisations (Switzerland), Energy Star database (US). Although for measuring on-mode power consumption of televisions an international standard is available (IEC 62087, Edition 2.0 2008-10), it was not always indicated whether this standard had been used in measuring the data. Since the revised standard has been adopted by industry and test laboratories, it was assumed that 2008 and 2009 data has been measured according to the 2nd edition. Anyhow data on LCD televisions, which nowadays dominate the market in most countries, is only available from 2007 as market shares before 2007 were insignificant. However the data on energy (efficiency) can only be considered illustrative. Furthermore, the Energy Star database by nature only represents the more efficient products and therefore could not be used as representative data for the US.

As energy efficiency metric the energy efficiency index (EEI) developed for the European energy label ([11] p. 69) has been used:

$$EEI = P_{on} / (P_{basic} + 4.3224 * \text{screen area})$$

where P_{basic} is 20 W[9] and the screen area is the visible screen area in dm^2.

[9] The final version of the regulation as published in the Official Journal differentiates P_{basic} for television sets with hard disk(s) and/or more than 1 tuner. However, the Mapping&Benchmarking results were based on an earlier draft version without this differentiation.

The reason for using this metric, instead of a straightforward power per screen area, is that for smaller televisions the power consumed by other parts than the screen, e.g. tuner, picture processing, is not negligible.

Benchmarking results

From the Swiss data that is available from 2000, it can be concluded that between 2000 and 2008 the screen diagonal increased by 40 %. For the years for which LCD television data is available, the screen size of LCD televisions increased by 1 % per year. The average new LCD television screen size in 2008 was 83 cm, while the average new plasma television screen size was around 110 cm.

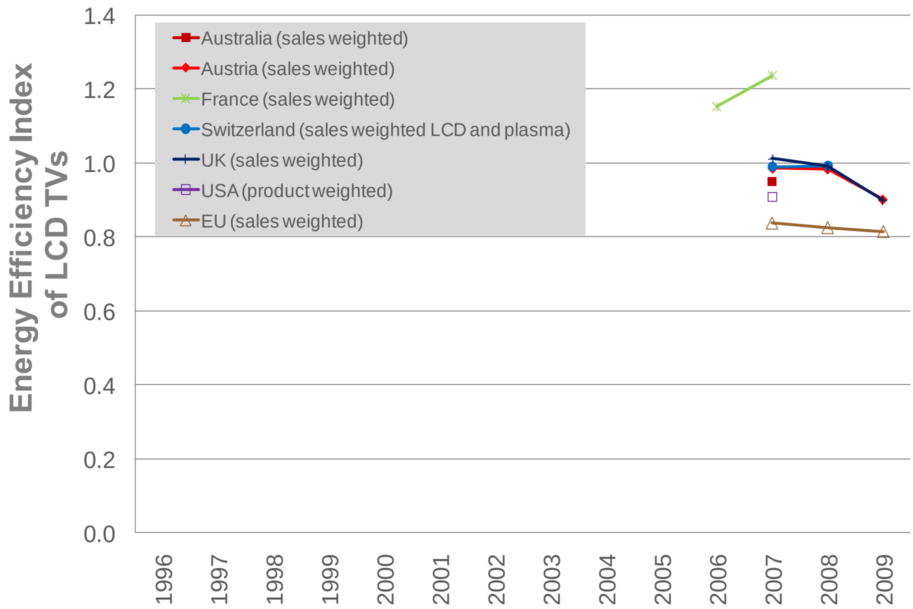


Figure 3. Average LCD energy efficiency index (illustrative) ([10] p. 25)

Figure 3 suggest that there is a downward trend, i.e. an improving energy efficiency of LCD televisions.

Standby consumption has fallen from an indicative average of 4.4W in 2000[10] to 0.6W in 2009[11]. Some national policies (Republic of Korea, USA) have directly addressed standby consumption for televisions over many years. However, much higher consuming (non-default) standby modes are becoming available, for example to enable rapid start (examples found include over 17W consumption for this mode).

Policy recommendations

Potential areas that policy makers might consider investigating include:

- To monitor the availability and prevalence of high consumption alternatives to standby mode, such as 'rapid start', and ensure that they do not fall outside the scope of current policies.
- To monitor consumption of emerging functionalities such as Internet enabled televisions, televisions with multiple tuners etc and ensure that these do not inflate national emissions nor fall outside the scope of current policies.
- As the control of total product consumption is likely not to be possible, policy makers could consider policy based on consumption caps or efficiency thresholds becoming significantly more demanding at higher screen sizes, to constrain overall consumption.

[10] Only data for Switzerland and UK available for that year.
[11] Only data for Austria available for 2009.

Air conditioners[12] - Results and Recommendations

Product definition

An air conditioner is an appliance for use in dwellings designed to maintain the temperature of indoor air at a given temperature level for a given heat load to be extracted ([12], p. 7). Ducted air conditioners (central) and single-ducted (portable) units are excluded from the analysis.

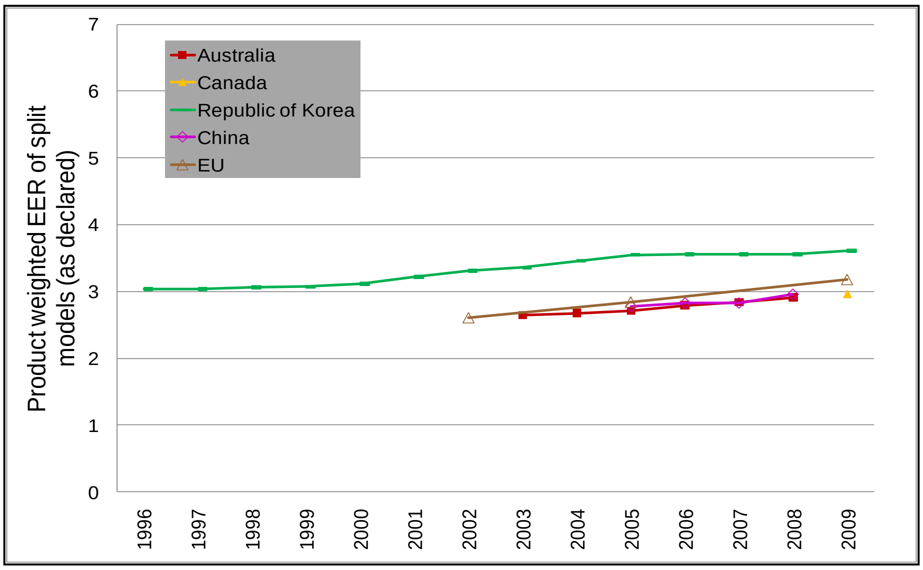
Data processing and normalisation

Data was obtained from several sources: mandatory government databases (Australia, Republic of Korea, Canada); US ENERGY STAR database; EU product data from GfK and the EUROVENT manufacturers' certification scheme, plus some high level market average data for China.

Apart from converting the data in the US and Canadian datasets from Btu/hr to kW, data from Korea was normalized to account for the indoor wet bulb temperature during test being 0,5 ^{o}C higher than used in other countries. From ([4] p11) it was concluded that lowering the EER results by 1,2 % and capacity results by 1,6 % would render the Korean results comparable.

Benchmarking results

Figure 4 shows benchmarking product-weighted results for the energy efficiency ratio (EER) for split



products.

Figure 4. Product weighted energy efficiency ratio (EER) for split products ([13], p.23)

Split products accounted for over 95 % of the EU market for products less than 14kW capacity in 2009. Figure 5 shows the EER of the most efficient split products.

[12] Only residential ir conditioners were included.

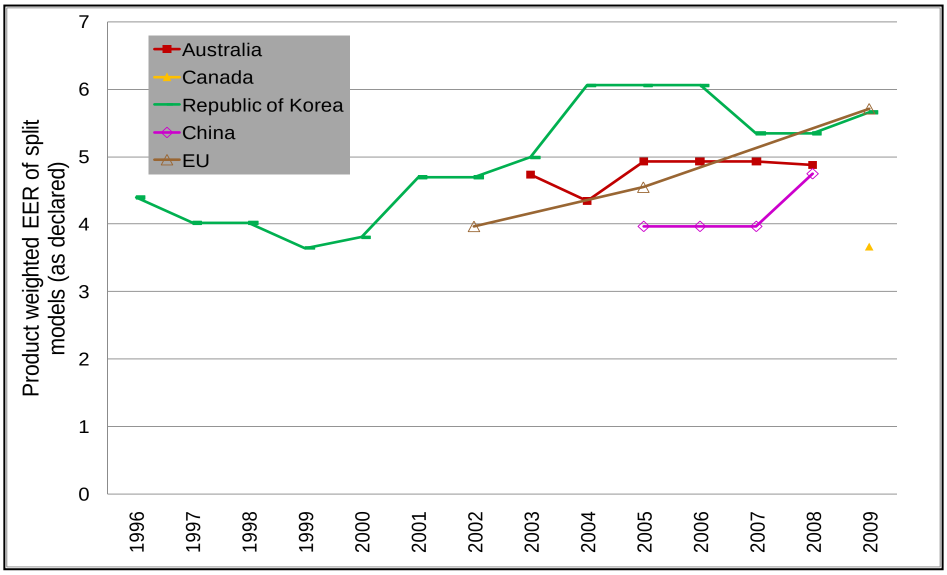


Figure 5. EER of the most efficient split products ([13], p. 26)

Substantive sets of sales weighted data for split products showed that the average EER for split products in Australia was very similar to that from Europe from 2005 to 2008 and these improved over that period by some 18%. But in 2008 the EU and Australia were still 8% poorer than the average for the Republic of Korea, which had declined very slightly over the same period. The efficiency of the most efficient products on the EU market (not necessarily products produced in the EU) increased from EER=3,97 in 2002 to EER=5,71 in 2009 slightly surpassing the most efficient products on the Korean market.

Another finding to note is that the proportion of products sold with variable speed or multi-speed compressors in the EU and Australia was at or approaching 50% by 2008, which should be making real in-use savings compared to single speed compressors.

Policy recommendation

- There appears to be significant scope for improvement in the full load efficiency of all but the very best of products, since average sales weighted EERs lie between 3 and 3.5, the best products are achieving over 6 and the theoretical maximum is around 6.5.
- The previous policy focus on use of Energy Efficiency Ratio (EER) and the analysis presented here probably underestimate the improvements that have actually occurred in real operation of better products. One of the major innovations in recent years has been the use of variable speed compressors, which provide better instantaneous EERs in cooler weather (when running at less than full capacity). The Seasonal EER (SEER) metric much better reflects real performance, and these improvements, and is now the focus of policies in most regions

Conclusions and recommendations

Lessons learned regarding data collection, processing and normalisation

The following lessons were learned regarding the **data collection and processing**:

- There is still a lack of readily available comprehensive time series data on energy efficiency of products. From the 10 countries participating in the Annex at the time, 9 countries were able to supply data for cold appliances (plus the EU and China). However, for most other products the number of participants able to source data is significantly lower. In general, only in countries where there is an obligation to report to a government database (Australia, Canada, US, Republic of Korea), is this data readily available. However, it should be noted that for fast evolving products, eg consumer electronics, even government databases do not necessarily provide perfect data sources as registration is not always required immediately and/or the development of required registration legislation does not keep up with product innovation. Hence, for such products, where the most recent information is required, data has to be sourced elsewhere, eg industry, advertisements, consumer test centres, etc. But clearly this can lead to distortion of outcomes as these datasets are rarely representative of the entire market.

- Data at the model level is the most easily and reliably manipulated data and allows for much more depth analysis than market aggregated data. Similarly, actual test data enables much more robust analysis rather than, for example, energy label classification which requires assumptions to be made about typical efficiency/performance within a classification.
- Data collection, cleaning and clarification is a time consuming task. Even if data is readily available it is mostly not available in the required format. This means that most raw data needs to be converted to a consistent/compatible form.
- Extreme caution has to be used when processing data, even when from the same source. Among other issues, when dealing with time series data it is important to check that the data is consistent in terms of market coverage and/or testing methodology and product classification.

Normalisation is necessary to enable comparison between data from different countries and/or for different years. The reason that normalisation is required is mostly that there are differences in test methods. Some of these differences are due to differences in the technical system, e.g. supply voltage and frequency, others reflect differences in use, e.g. ambient temperatures. Good test methods will reflect as accurately as practicable how the product is used in the home in order to drive innovation towards better efficiency in use. Whilst usage patterns may vary by region and so require variation in test method, the challenges in normalising for example washing machine and tumble dryer test results imply that methodologies are fundamentally divergent. However one practical result of this is that energy efficiency innovations, or conversely poor product performance, in one region may not be evident and so could hamper transfer of best practice. Another risk from differences in test methodologies for similar products could be mistaken policy conclusions from comparison of performance (and/or MEPS) without normalisation.

Normalisation is in most cases possible and can yield useful results to show more fairly how the efficiency of the products/technologies compare between regions. For some products this has proven time consuming and complex, both to understand what fundamental differences exist between methodologies, and how best to normalise for multiple differences. However for “regional” test methodologies, e.g. for cold appliances, the results must be used with caution.

Issues on data collection for policy-making

Policy makers want to compare products between countries; as stated this is complicated by the divergence in test standards (normalisation) however, the issue is compounded by non-consistent data collection. To take refrigerators as an example, critical data required to make any kind of effective comparison between countries is:

1. Type of unit (refrigerator, refrigerator with ice box, fridge freezer combination.)
2. Compartment size of unit (size of each unit: icebox; fridge; freezer)
3. Energy consumption of unit under test conditions

Unfortunately policy makers sometimes forget this need in the development of local reporting/registration requirements. Hence, the only data that is sought or captured locally is orientated to local standards, eg the declared EU label level or US standard energy consumption, neither of which allow the computation of actual unit energy consumption per volume cooled without specific knowledge of the unit. Clearly additional data (configuration of fridge freezer combination, inclusion of ice maker, etc) enables more robust analysis, but ensuring the very basic product level information is recorded would enhance policy development and evaluation of impact. Similar examples apply to other projects such as:

TVs:

- Energy performance data to test methodology (IEC 62087 Edition 2) should be collected (the test standard has been globally adopted and which also gives results reasonably representative of home use.)
- It would be valuable to track both on mode consumption and energy efficiency (perhaps usefully in the form of an Energy Efficiency Index that compensates for screen size).
- In order to track and understand trends which vary between different technologies, it would be advisable to collect data separately on LCD and plasma televisions, and at later stages on rear projection, OLED and other technologies as they become significant in the market.

Air conditioners:

- SEER can be a more effective metric than EER in terms of making real energy savings.
- Evidence from Australia implies that standby consumption can be up to 40 W constantly, powering the crankcase heater as well as electronic controls. So this should be monitored and recorded as well as EER/SEER.

References

[1] Battles, Stephanie J. and Behjat Hojjati, Two Decades of U.S. Household Trends in Energy-Intensity Indicators: A Look at the Underlying Factors, June 2005.

[2] Boteler, R. etal., Motor MEPS Guide, Zürich, 1st edition, 2009, http://www.motorsystems.org/downloads

[3] www.topten.info

[4] APEC-ESIS report: Benchmarking Of Air Conditioner Efficiency Levels In Five Asian Countries, Prepared For The Australian Greenhouse Office, Danish Energy Management, June 2004.

[5] Bertoldi, P., B. Atanasiu, Electricity Consumption and Efficiency Trends in the European Union, JRC, Luxemburg, Publications Office of the European Union, 2009, p13.

[6] 4E Mapping & Benchmarking Annex, Framework for Product Definition, Data Collection, Data Analysis and Outputs, http://mappingandbenchmarking.iea-4e.org/, 22 June 2009

[7] European Parliament, Directive 2009/125/EC of the European Parliament and the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast), OJ L285, p.10-35, 31.10.2009 p9

[8] Kemna, R.B.J. etal, MEEUP Methodology Report, Van Holsteijn en Kemna for European Commission, Delft, 28 November 2005, p.18

[9] 4E Mapping & Benchmarking Annex, Benchmarking of Domestic Cold Appliances, http://mappingandbenchmarking.iea-4e.org/, 23 August 2010

[10] 4E Mapping & Benchmarking Annex, Benchmarking Document Televisions, http://mappingandbenchmarking.iea-4e.org/, October 2010

[11] European Commission, Commission delegated regulation No 1062/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and the Council with regard to energy labelling of televisions, OJ L 314 p.64-80, 30.11.2010

[12] Riviere, P. et al., Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) Task 1 Ecodesign Lot 10, Armines, March 2008.

[13] Mapping & Benchmarking Annex, Benchmarking Document Air conditioners, http://mappingandbenchmarking.iea-4e.org/, January 2010

Enforcement of energy efficiency regulations for energy consuming equipment: findings from a new European study

Paul Waide[a], Rowan Watson[a], Anita Eide[b] and Michael Scholand[c]

[a]Navigant Consulting Europe

[b]CLASP Europe

[c]N14 Energy

Abstract

Like other major economies, the European Union applies a variety of energy labelling and minimum energy efficiency standards regulations to energy using equipment. Each EU and EEA Member State has responsibility to enforce these regulations; however, in practice the level of enforcement effort varies substantially from one economy to another while the loss of cost-effective energy savings through weak enforcement effort across Europe as a whole remains significant. This paper reports the results of the most detailed study yet undertaken into enforcement with European equipment energy efficiency regulations, which is based upon a very detailed assessment of the state of enforcement in each individual EU economy. It examines the legal basis for enforcement, the institutional arrangements to ensure compliance, the technical competence of entities responsible for compliance, the procedures to be followed to monitor the market and in the event of non-compliance, the penalties applied for non-compliance, the resources committed to enforcement and the degree of cooperation over enforcement between EU Member States. It further assesses the extent of energy losses and costs attributable to imperfect enforcement for each economy and determines the extra savings that would be associated with a stronger enforcement effort as well as the expected benefit-costs from doing so. Lastly, it presents new thinking on practical and politically viable means of strengthening enforcement at an affordable cost and sets out a viable pathway to substantially improve the situation across Europe as a whole.

Introduction

Navigant Consulting and its partners SEVEn and SoWatt, were commissioned by CLASP Europe to undertake a study on the monitoring, verification and enforcement structures, programmes and policies relating to the European Energy Labelling and Ecodesign Directives across the European Union’s Member States.

The subsequent study was executed through literature reviews, internet research and a comprehensive survey of stakeholders within the Energy Labelling and Ecodesign domain, which included central governments and government departments, consumer associations, energy agencies and testing laboratories. A detailed report documenting the nature of compliance activities was produced for each of the EU and EEA countries, making 30 countries in total.

For each country the following tasks were undertaken:

- a complete list of legislation of the transposition and implementation of both Directives was obtained,
- a map of the institutions involved in compliance was produced, documenting institutional roles and mandates and linkages

- the capacity of each institution to fulfil their compliance function was assessed
- the frequency, type and scale of compliance testing activities under the Directives was assessed
- the scale of, and barriers to, international cooperative activities were assessed
- the nature of non-compliance procedures and penalties were documented

In addition to the above, an assessment of the value of full compliance was produced and compared to the resources currently allocated to compliance and the expected benefits of higher compliance.

Transposition of the legislation

All but one Member State and EEA has transposed the Energy Labelling and Ecodesign Directives into their national laws. The legislative and administrative functions were generally well planned and executed whereas the monitoring, verification and enforcement functions were either in their infancy or not undertaken at all. Responsibilities in most cases had been distributed and were transparent, but their physical activities were less well defined.

The table below shows the law used by each Member State and EEA to transpose the Energy Labelling and Ecodesign Directives and the date of the transposition.

Table 1. Date of Transposition of Directives by Country and Law Used

Country	Energy Labelling – 92/75/EEC		Ecodesign – 2005/32/EC	
	Date of Transposition	**Law used to Transpose**	**Date of Transposition**	**Law used to Transpose**
Austria	1998	Electrical Engineering Legislation	2007	Electrical Engineering Legislation
Belgium	1996	Commercial Law	2007	Environmental Law
Bulgaria	2006	Ordinance on the labelling requirements of the consumption of energy and other resources by household appliances under the Consumer Protection Act.	2007	Technical Requirements towards Products Act (TRPA)
Cyprus	2001	The Indication of the Consumption of Energy and Other Essential Resources By Household Appliances	2007	Ecodesign requirements for energy-using products law
Czech Republic	2001	Commercial Law (Energy Act and Energy Management Act)	Various 1997-2008	Commercial Law (Energy Act and Energy Management Act)
Denmark	1993	Energy Law	2008	Energy Law
Estonia	2004	Energy Efficiency of Equipment Act	2008	Energy Efficiency of Equipment Act
Finland	1994	Act of Ecodesign and Energy Labelling of Products	2009	Act on Ecodesign and Energy Labelling of Products
France	1994	Consumer Protection Law	2007	General Environment Law

Germany	1997	Energy Law	2008	Commercial Law
Greece	1997	Presidential Decree 180/1994	2007	Presidential Decree 32/2010
Hungary	2002	Consumer Protection Law	2007	Consumer Protection Law
Iceland	1994	Act on Ecodesign of Energy Using Products No 42/2009	2009	Law amending law no. 72/1994, labelling and disclosure requirements relating to household appliances energy use
Ireland	1995	European Communities Act 1972	2007	European Communities Act 1972
Italy	1998	General Law No. 107	2007	General Law No. 201
Latvia	2004	Consumer Protection Law	2007	Environmental Law
Lithuania	2003	Technical Regulation on indicating standard product information by labelling the consumption of energy and other resources for household appliances	2007	Technical Regulation on establishing a framework for the setting of Ecodesign requirements for energy using products
Luxembourg	2009	Product Surveillance Legislation	2008	Product Surveillance Legislation
Malta	2002	Product Safety Act	2007	Product Safety Act
The Netherlands	1992	Law on Energy Saving of Appliances/ Commercial Law	2007	Dutch Law of Environmental Governance
Norway	1996	EEA Agreement with the Norwegian Act relating to the Labelling of Consumer Goods.	Expected in 2011	Had not been transposed at the time of publishing
Poland	1997	Energy Law	2007	Energy Law
Portugal	1997	Consumer Protection Law	2009	Consumer Protection Law
Romania	Various 2002-2006	Energy Efficiency legislation	2007	Judgement on Ecodesign Requirements for Energy Using Products and Amending, Supplementing and Repeal of Laws
Slovakia	1999	Acts within Conformity Assessment Law	2007	Acts within Conformity Assessment Law
Slovenia	2001	Energy Law	2008	Energy Law

Spain	1994	Consumer Protection Law	2007	Royal Decree 1369/2007, of 19 October on the establishment of Ecodesign requirements for energy-using products
Sweden	1994	Law 92/1232 on the Labelling of Household Appliances and Regulation, and 1994:1774 on the Labelling of Household Appliances	2008	Law 2008:112 on Ecodesign.
United Kingdom	1994	Energy Conservation Law	2007	Energy Conservation Law

Source: Navigant, 2010 [1]

The recast Energy Labelling framework Directive 2010/30/EU was extended to cover more products and include products in the commercial and industrial sectors. It also added energy classes A+ to A+++ on top of the A rating for televisions, refrigerators, dishwashers and washing machines. Refrigerators, vending machines and display cabinets in the commercial sector and televisions, refrigerators, dishwashers, washing machines, water heaters, boilers and air-conditioners in the residential sector are being planned for legislation. The Commission is also working on the adoption of new energy labels for lighting, air conditioning, laundry driers, water heaters, boilers and vacuum cleaners. At the time that this study was carried out only one country had transposed the 2010 recast into national law (according to the European Law portal EUR-Lex), this was Estonia through Toote nõuetele vastavuse seadus (Product Conformity Act) - Legal act: seadus, number: RT I 2010, 31, 157; Official Journal: Elektrooniline Riigi Teataja, number: RT I 2010, 31, 157, Entry into force: 01/01/2011; Reference: (MNE(2010)57049).

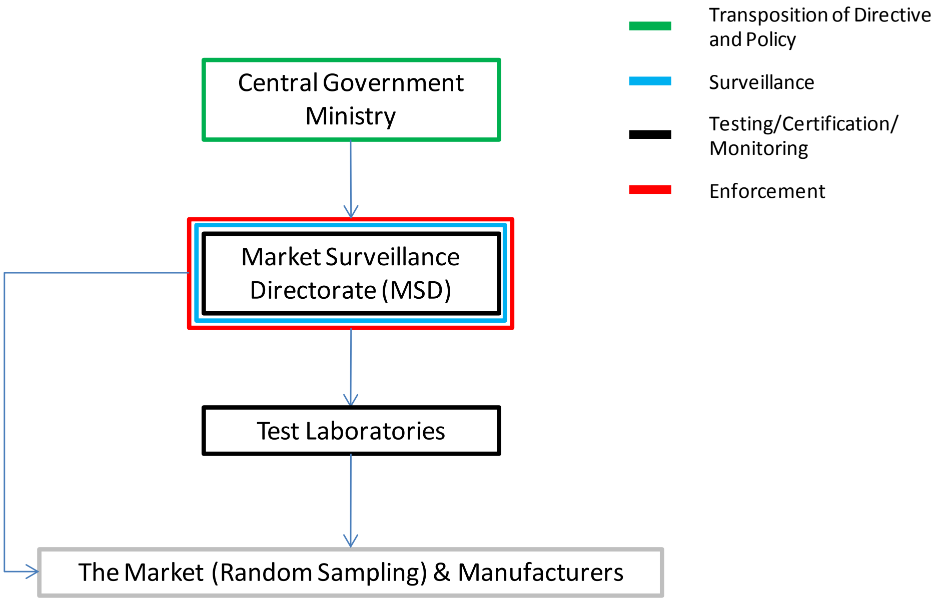
According to EUR-Lex, the recast Ecodesign Directive 2009/125/EC (which extended its scope to all energy-using products) has been transposed by Cyprus in 2011; Denmark (2010); Estonia (2010/11); Finland (2010); France (2010); Greece (2011); Lithuania (2010); Luxembourg (2010); Malta (2010); Poland (2011); Portugal (2011); Romania (2011); Slovakia (2010); The Netherlands (2010); and United Kingdom (2010). Future plans for Ecodesign include a further indicative list of product groups (10 in total) which are described in the working plan for 2009-2011 under the Ecodesign Directive. A preparatory study is being planned for each of these products between 2009 and 2011.

Institutional arrangements

The majority of the countries interviewed had clearly defined the roles of the institutions/stakeholders involved in MV&E. The capacity of those institutions however, varied considerably between countries. Broadly speaking, a Central Government department (often called a Ministry) was responsible for the transposition of the legislation; a delegated Government department sitting beneath the Ministry (often referred to as the market surveillance authority) was then responsible for compliance activities such as shop inspections and reviewing technical documents and in most cases enforcement also; testing was generally carried out by accredited laboratories after being instructed by the market surveillance authority. The share of responsibility was generally the same for Energy Labelling and Eco-Design but the role of a separate Government Agency which reported to a Government department such as an Energy Agency played a larger role in Energy Labelling. Denmark and Norway have set up/tasked a specific institution; Energy Labelling Denmark and Infratek Elsikkerhet AS, to manage the surveillance role under the Directive. Consumer Associations played a small role in the Directives some assisting with surveillance activities (Belgium, Cyprus, Greece, Italy and Luxemburg), and some countries

(Germany and Spain) delegate all compliance responsibilities except transposition to the federal states within their countries.

Figure 1. Typical Institutional Arrangement for MV&E Activities under the Energy Labelling and Ecodesign Directives



Institutional capacity

As mentioned in the previous section, the capacities of these institutions vary considerably in terms of resources and budgets. Many economies lacked clarity regarding the financial resources committed to their MV&E programmes, this may be due to a split in responsibility across agencies but more likely suggests that the information on the budgets is not readily available.

Most countries allocate some resources to the Directives, some are shared between both Directives (France, Hungary, Norway, Sweden) but most have allocated staff specifically for duties under either Energy Labelling or Ecodesign.

Under Energy Labelling some teams have very small capacities i.e. less than 1 FTE (Cyprus, Czech Republic, France, Greece, Iceland, Ireland and Malta) although these tend to be the smaller economies and some have large numbers of staff at their disposal, Slovakia has 10 FTE, The Netherlands have 3.5 FTE, Spain have 2-3 FTE in Central Government and 0.5 FTE in each region, Austria has 2 full time and 3 part time in Government and agencies and the UK has 3 FTE. Inspectors are generally available to most institutions on an ad hoc basis and are not counted as full time staff.

For Ecodesign compliance activities small numbers of staff exist in the countries previously mentioned under labelling, plus Estonia, and larger numbers in Austria (2 FTE in central government and 2 part time in the responsible agency) Denmark (3 FTE), Germany (13.5 at Federal level split between two organisations), and the UK (3 FTE).

Annual budgets for Energy Labelling compliance activities range from €1.2k (Luxembourg) to around €390k (Denmark). For Ecodesign compliance budgets range from less that €1k (Iceland) to €500k (Denmark). The larger combined compliance budgets, i.e. over €500k, are seen in Denmark, Norway, Sweden and the UK. Sweden's large budget, €180k for market surveillance and €650k for testing, is split between both Directives so it is unclear how it is distributed. Many countries are reluctant to share budgetary figures so conclusions can only be drawn from a sample.

Across the EU we tentatively estimate that there are about 80 full time equivalent staff working on Ecodesign and energy labelling compliance administration in the 27 Member States and perhaps the same level (optimistically) involved in store inspection to ensure labelling compliance. Total

Community wide annual expenditure on compliance appears to be between about 7 and 10 million Euro.

Scale of compliance testing

Testing is heavily dependent on the availability of laboratories, accredited or otherwise. At the time of interview the following countries had no operational accredited laboratories: Austria; Belgium; Cyprus; Iceland; Ireland; Latvia; Lithuania; Luxembourg; Malta; Portugal; Romania; and Slovakia. This represents 41% of the countries interviewed. Of these countries, some looked outside to foreign to laboratories to undertake tests on their behalf (Austria, Iceland, Ireland, Luxembourg, Romania and Slovakia), some also stated that they were in the process of arranging for accreditation for their domestic laboratories (Austria and Ireland).

The Danish laboratory DTI is used by the Governments of Norway and Sweden to perform tests under the Directives. These are good best practice examples of overcoming capacity restrictions in countries that wish to undertake testing.

Because of the comparable infancy of the Ecodesign Directives to Energy Labelling, testing under the Ecodesign Directive was fairly limited. For Energy Labelling more testing has been undertaken as part of monitoring and surveillance activities.

Of the 17 countries with accredited laboratories, only 7 currently conduct verification tests (Denmark, Germany, Hungary, The Netherlands, Spain, Sweden and The United Kingdom). Of these 7 countries most performed testing on the full range of products covered under Energy Labelling making it hard to determine whether one product was favoured over another. Of the 7 countries conducting testing only 4 have undertaken testing under the Ecodesign Directive: Denmark (preliminary testing only), Germany (stand-by and lamps), The Netherlands (stand-by is being planned) and the United Kingdom (products unknown).

Across the EU as a whole we estimate that there are between 800 and 1500 product energy conformity tests done for official compliance purposes per year.

Levels of non-compliance

Types of non-compliance under the Energy Labelling Directive include: mixed labels (e.g. label for a refrigerator placed on a washing machine); label in a foreign language; no label; the sticker with the equipment’s specific energy data was an inadequate size (it did not match the size of the energy label base grid for that appliance type, making it difficult to read); energy label used was a carbon copy; data was handwritten on the energy label (making it less credible); reuse of labels (stickers glued on top of each other; sometimes the information corresponding to the previous equipment, under the last sticker, was still legible); and noise level of equipment is not indicated (particularly in washing machines and air-conditioners) –although it is not always clear whether that qualifies as non-compliance.

The reported EU average for unlabelled appliances is 20 – 30% [2].

The largest retailer and manufacturer survey undertaken to date has been the Fraunhofer Report in 2009. Fraunhofer interviewed all Member States and conducted surveys on retailers in the various countries. The results from the retailers varied considerably, from 26% to 90%. Fraunhofer also asked stakeholders what they considered compliance to be, invariably they answered higher than the survey results. Compliance was also noticed to be higher in larger chain stores in towns than when compared to smaller stores out of town, regardless of the country.

Manufacturer compliance is a little harder to gauge without testing which the majority of countries do not undertake. Fraunhofer classified compliance for manufacturers as low, medium, high based on interviews with stakeholders, again results varied across Europe. For those countries not undertaking verification testing, the justification provided was that it was deemed either: too expensive; the market was considered too small; MV&E budgets were too constrained; not enough resources; no access to accredited laboratories; and testing procedures were considered too complex. When this was the case many countries only engaged in testing as a result of a complaint which was satisfactory for their requirements.

Monitoring of the internet and catalogue offers also varied by country. The main reason proffered for a lack of consistent mass checks for these mediums was that the internet and catalogue sales volumes are low and not considered to be a common route to market at present. Thus it is suggested that attributing resources in the form of employees or budget would not be effective or justified [3].

Of the countries that did undertake verification testing:

- Denmark - 50-60 products were systematically tested under the Energy Labelling Directive in 2010 and only CFL's and technical document assessments for Ecodesign

- Germany - Ecodesign only at State level – around 400 products by October 2010 in Hessen including lamps, televisions, refrigerators, EPS, and those covered by the stand-by regulation

- Hungary - 200 appliances a year from all product groups, with between 3 and 5 reported cases of non compliance under the Energy Labelling Directive

- The Netherlands – about 75 appliances are tested for Energy Labelling compliance each year of which the majority are washing machines, ovens and refrigerators. It is reported that 98% of the appliances are classified correctly [4]. Ecodesign testing is still in the planning stage and Stand-by power consumption in consumer electrical appliances was due to be tested towards the end of 2010

- Spain - through the RENOVE subsidy programme (details below)

- Sweden – Under an Energy Labelling Directive 2010 testing programme the following appliances were tested by the Danish Technological Institute: freezers (90% compliance), washing machines (90%) and tumble dryers (100%)

- UK – 20 to 100 units a year from all product groups - typically only 10 % are classified correctly if permitted tolerances are discounted, but the tolerances are too large, so that 80 % are classified correctly if the 15 % permitted tolerance limits are applied

Some observations follow:

Outside of the Eco Design and Energy Labelling Directives, Spain also has other programmes that encourage the adoption of energy efficient appliances. For example, the "RENOVE plan", now in its fifth cycle, works to subsidise the replacement of old appliances with new efficient models. The RENOVE plan is managed by the regional governments who allocate a fixed annual budget to encourage the selection of efficient appliances within the official database of IDAE. This restriction ensures that only appliances that have been tested and verified can be supported by the subsidy. The level of the support is approximately €100-130 per appliance. The retailer receives the rebate, and the cost for the consumer is discounted. This is a substantial programme in Spain, where between 2006 and 2008, 1.8 million electric appliances were replaced under the scheme, of which 48% were washing machines, 38% fridges, 11% dishwashers and the remaining 3%, freezers.

The central Government, mainly the IDAE selected appliances from the Plan RENOVE programme, purchased them and then tested them to ensure that the energy class and performance data presented on the label are correct. Through monitoring of the database, IDAE estimates that approximately 75% of the products are correctly labelled and 25% of the products are removed from the list [5].

This programme is an example of one of the initiatives working to improve the level of supplier compliance with the energy label and addresses both the presentation of the label on the appliance in retail shops and the technical performance reported on the label itself. If the programme has a specific energy efficiency requirement for a model to be included, manufacturers have to submit the documentation to the programme organisers for inspection.

In the UK Defra noted that testing of consumer products is time consuming, expensive and it can be difficult to find specialist laboratories able to conduct the tests. Typically, if permitted tolerances are discounted only 10 % of products would be deemed to have their declared energy label class; however, this is largely a function of the legally permitted tolerances being overly generous and of producers taking advantage of this as about 80% of products were found to be properly classified if the 15 % tolerance limit is applied.

Penalties for non-compliance

Penalties under the Directives typically consist of warning letters; fines; prosecutions; and judicial sentences; warning letters and fines being the most common course of action. Fines vary by country and by Directive, Ecodesign appearing to carry heavier fines than Energy Labelling. Fines are sometimes very difficult to administer due to the interaction with other parties and often it costs more to administer the fine that the fine itself, particularly when the fines are modest.

In Denmark, a new course of action that has not been trialled yet is that if the Government can show that there has been extra earning as a result of the mislabelling/ misrepresentation of an appliance, they can confiscate the money earned. This approach could be hard to prove and might explain why there have been no cases of its use yet [6]. Another popular and effective course of action is to 'name-and-shame' non-compliant manufacturers and retailers through websites and press releases. This approach is considered more powerful than any other approach due to the damage to reputation. Sometimes even the threat of publishing test results is enough to provoke a manufacturer to change their product's label information.

The enforcement of the Directives comes up against some barriers for example when manufacturers are not a part of Conseil Européen de la Construction d'appareils Domestiques (CECED) there is a problem with enforcement [7]. This is due to the parties responsible, mainly from China, being more challenging to make contact with and the importers not being considered legally responsible [8].

The Market Inspectorate of Slovenia reported that Slovenia had problems implementing a penalty system and it took two years to put a system into place. Clarity of the existing laws was needed. According to reports from the Market Inspectorate, administrative checks were conducted on energy labelling and the Energy law is currently under reconstruction [9].

Very few countries have taken legal action as a result of non-compliance under the Directives, of those that have some examples follow:

A recent high profile enforcement case in Sweden involved Samsung freezer model RZ80EESW labelled class A+ [10]. The product was tested and was found to only meet the requirements for Class B. The Swedish Energy Agency was alerted to this non-compliance by Bosch, illustrating the influence market competition can have on driving up compliance levels. The Swedish Energy Agency issued Samsung a penalty order for €500k with demands to re-classify the model as class B or improve its energy performance. In response, Samsung withdrew the model from the market and avoided paying the fine, even though 15,000 non-compliant freezers had been sold up to that point. It is interesting to note that the Swedish Energy Agency shared the non-compliance information with the Danish Energy Agencies, who collaborated with Sweden and were involved in the ensuing negotiations with Samsung Nordic [11].

The UK recently had a successful prosecution against a freezer importer who had false energy labels on their products. In August 2010, the Northamptonshire County Council's Trading Standards Office successfully prosecuted a retailer for advertising and selling chest freezers with incorrect energy labels. John Gillman and Sons (Electrical) Limited of Gloucester pleaded guilty to six offences contrary to regulation 9 of the Consumer Protection from Unfair Trading Regulations (2008). They were fined £5,400 and court costs of £9,400.

Benefit-cost value proposition of higher compliance

The costs incurred by poor compliance (in terms of energy, CO2 and economics).

The EU has a well documented target of reducing its primary energy use by 20% in 2020 compared to business as usual projections. Energy efficiency improvement is placed firmly at the heart of EU

Energy policy and according to Commission thinking Ecodesign and energy labelling are intended to produce 25% of this overall objective. Nonetheless, recent Commission estimates suggest that the EU is on course to achieve only half of the 20% savings objective.

The combined effects of full implementation of the existing and new measures will transform our daily life and have the potential to generate financial savings of up to € 1 000 per household11 every year; improve Europe's industrial competitiveness; create up to 2 million jobs12; and reduce annual greenhouse gas emissions by 740 million tons13

It's been estimated that at least 25% of the EU's total energy savings objectives need to be met by the combined impact of the Ecodesign and Energy Labelling efforts. Ecodesign measures have been issued for twelve product groupings already and measures are under development or consideration for another 34 products. The products already subject to measures are projected to consume almost 2000TWh of electricity by 2020 and give rise to 839Mt of CO2 emissions, whereas the entire set of products under consideration will have a much higher consumption.

Furthermore a new Ecodesign plan for 2012-14 is under development which considers priorities among all energy using and many energy consumption influencing products. For the products already subject to regulations the Commission has estimated that the total yearly savings by 2020 should total 341 TWh of electricity demand and 143 Mt of CO2; however, as more products are added these savings should increase by between a factor of 2 and 4. The Ecodesign and energy labelling measures are among the most concrete energy efficiency policy measures yet implemented or being countenanced and thus they form a central plank of the Community's energy conversation plans. Given this context it is germane to consider how adequate the existing enforcement effort is and whether or not sufficient resources are being committed to it. One means of doing this is to assess the value of the energy likely to be lost through poor compliance. As already alluded to the compliance data currently available is patchy and so it is difficult to draw a clear picture of the current degree of non compliance. Based on the detailed assessments reported in the UK and discussed at the IEA 4E workshop on compliance [13] the typical level of energy lost through non-compliance is likely to be at least 10% of the value of the total energy savings and probably greater than this.

As a working assumption if we estimate that by the time Eco-design measures are put in place for the current products under consideration in the Ecodesign process that expected savings in 2020 will be about 700 TWh of final electricity demand. If 10% of this would be lost under the current compliance regime it would amount to 70TWh of lost savings annually in 2020. At current energy prices this would be worth about 9.5 billion Euro per year or roughly €20 per capita. Thus current expenditure on compliance with energy labelling and Ecodesign across the EU is roughly one thousandth of the value of the lost energy!

It is not clear how much additional compliance would be ensured from incrementally increasing compliance efforts but there is clearly a huge scope for cost-effective increase in compliance expenditure at the societal level. As a first rule of thumb we would propose that states should certainly not be spending less than €1 per capita on product energy performance compliance. Although this would constitute a 50-fold increase over current average EU compliance expenditure, it is still only a 20th of the value of the currently projected energy losses. Such expenditure could be expected to increase compliance by at least 50% and hence would still be highly cost-effective from a societal stand point.

How could things be improved?

Like previous studies into this area this latest effort has confirmed that at best product energy performance compliance efforts in Europe can be described as half-hearted. A number of barriers to improving compliance were identified through the study. The key ones being: inadequate funding and capacity of the institutions responsible for carrying out monitoring, verification and enforcement activities; weak penalties for non-compliance; lack of transparency regarding compliance activities and lastly a lack of awareness among consumers such that manufacturers and retailers do less likely to fear being 'shamed' in the media. Overall these problems stem in large part from a lack of prioritisation of MV&E activities among central Governments. In general, the system is assumed to be working and whenever faults are detected they are liable to be blamed on individual parties, retailers, manufacturers, agencies rather than the collective.

Compliance levels seem to vary significantly and even in the Member States with the most comprehensive compliance efforts the coverage by product type is not comprehensive. In some Member States the coverage is minimal or non-existent. As progressively larger lists of products are added to the Ecodesign and Energy Labelling portfolios the coverage of compliance programmes and the availability of accessible testing facilities is set to become a progressively greater concern.

Across the EU as a whole expenditure on ensuring product energy performance compliance is estimated to be roughly one thousandth of the likely value of the extra energy consumed due to poor compliance. Thus the investment case for strengthening compliance is clear. There is a need to educate finance ministries of this lost opportunity so the broader macro-economic arguments can be considered in resource allocation decisions.

At present the financial penalties imposed for non-compliance are generally rather weak and hence their deterrent effect must be questioned. The main deterrent value appears to be the risk of bad publicity from being found to be in breach of EU legal requirements; however, some suppliers with greater brand value are likely to be more susceptible to this concern than those that sell to private label or OEM markets and thus some part of the market may only be weakly affected by brand value concerns. It is interesting to compare penalties applied in the EU to those in place in the US. In the latter the authorities have the possibility of applying fines of up to hundreds of dollars per non-compliant product sold on the market and thus the cost of a proven case of deliberate non-compliance could be so large as to effectively bankrupt a perpetrator. Such penalties do not appear to be available to EU regulators and thus the need to have a more comprehensive market surveillance effort becomes that much greater.

Aside from the obvious opportunities of increasing national resource allocations for compliance activities and strengthening penalties for non-compliance our stakeholders presented a number of suggestions to overcome the barriers identified. These included: strengthening the role of the ad hoc committee of Member State compliance agencies, ADCO, and encouraging more Intelligent Energy Europe led compliance support projects; greater information sharing and cooperation between countries, which would particularly benefit countries with limited or no access to accredited laboratories; increase financial support for responsible institutions operated by the EU or EC; subsidise/standardise the cost of testing – this makes MV&E plans easier to budget for and is more inclusive for countries with very small budgets for these activities; simplify the MV&E procedure as some stakeholders/manufacturers/retailers do not understand their role and specific responsibilities; make labels more adhesive as some stakeholders claim they fell off the products easily and were not replaced by retailers; more manufacturer inspections generally; testing at a European level; and finally storing key documents such as technical files on line, making them easier to access by enforcement staff as and when they require them.

- increase the fines for failing to comply with the Directives and thereby increase the incentive to comply;
- Our own recommendations include these but emphasise the following:
- Resource allocations for compliance activities need to be greatly increased to a level of at least €1 per capita per annum.

If increased central funding is not possible through central taxation governments might wish to consider funding compliance activities through energy efficiency schemes such as energy efficiency obligations or white certificate programmes

The extra resources should be spent on expanding verification testing (both for the number of products being tested and the range of products being tested), on strengthening market surveillance for energy labelling and on managing prosecutions and publication of non-compliance and other non-compliance procedural processes

To increase the effectiveness of compliance efforts governments should consider significantly increasing penalties for non compliance

Member States cooperation could be greatly facilitated were all products and their variants sold in the EU to be registered in a central database and national compliance testing results to be shared such that other member states could minimise duplicative testing.

Record keeping in general would benefit from greater standardisation and consistency to ensure commonality of procedures and reporting templates

References

[1] Navigant Consulting (Europe) Ltd. *Monitoring, Verification and Enforcement Capabilities and Practices for the Implementation of the Ecodesign and Labelling Directives in EU Member States*. London, UK. 2010

[2] Personal Communication between SEVEn and representatives of the Ministry of Industry and Trade, State Energy Inspectorate, Czech Trade Inspectorate, Ministry of Environment, Prague Energy Utility, Consumer association D Test, and CECED CZ, Prague, Czech Republic, October and November 2010.

[3] Kreitz, T., *Deliverable 2.2 - Overview of the methodology and the results achieved in the conformity assessment action at EU Member States and international level. Appliance Testing for Energy Label Evaluation* (Atlete), Rome, Italy, 2009. Retrieved from Atlete and Intelligent Energy Europe, http://www.atlete.eu/.

[4] Fraunhofer Institute for Systems and Innovation Research, GfK Marketing Services GmbH, BSR Sustainability GmbH, Karlsruhe, Nuernberg. *Survey of Compliance Directive 92/75/EEC (Energy Labelling)*. (Project Reference No. TREN/D3/238-2006 OJEU 2007/S 124-150987 of 30/06/2007). 4 January 2009.

[5] Personal Communication between SEVEn and Instituto para la Diversificacion y Ahorro de la Energía (IDAE), Madrid, Spain on 29 October 2010.

[6] Personal Communication between Navigant and Dansk Varefaktanævn (DVN), Copenhagen, Denmark, 13th October 2010.

[7] Kreitz, T., *Deliverable 2.1 – Report on the national legislations regarding energy labeling.* 2009. Appliance Testing for Energy Label Evaluation (Atlete), Rome, Italy, 2009. Retrieved from Atlete and Intelligent Energy Europe, http://www.atlete.eu/.

[8] Personal Communication between Intertek and Energia Központ Nonprofit Kft, Budapest, Hungary, 5th October 2010.

[9] Personal Communication between Navigant Consulting and the Market Inspectorate of the Republic of Slovenia, Ljubljana, Slovenia, between 22nd October to 12th November 2010.

[10] Blomkvist, O. Samsung Energibluff. Article dated October 29, 2010. Retrieved from http://www.realtid.se/ArticlePages/201010/28/20101028143530_Realtid182/20101028143530_Realtid182.dbp.asp

[11] Personal Communication between Navigant Consulting and the Danish Energy Authority, Copenhagen, Denmark, 8th November 2010.

[12] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Energy Efficiency Plan 2011 Brussels, 8.3.2011 COM(2011) 109 final.

[13] International Monitoring, Verification and Enforcement Conference, London, 14-16 September 2010, IEA Efficient Electrical End-Use Equipment Technology Agreement, http://www.iea-4e.org/events-and-meetings/compliance-conference

Establishing the German Ecolabel Blue Angel as national Label for Climate Protection on Domestic Appliances and Consumer Products

Dietlinde Quack, Jens Gröger

Öko-Institut / Institute for Applied Ecology, Sustainable Product and Material Flows Division

Abstract

Climate protection is one of the main challenges of this century. This has been accepted as consensus in society and each individual tries to make a contribution to this effort. But the key energy-saving opportunities are often associated with large financial or habit-related barriers, as e.g. improving the energy performance of buildings or the switch from private motor vehicle to public transport or bicycle. Climate protection therefore requires low-threshold offers to reduce the individual carbon footprint. At his daily purchasing decision the consumer must be enabled to pick the best product in terms of climate protection and to influence the market by his conscious consumption. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) recommends in a memorandum about Product Carbon Footprint the well-established Blue Angel eco-label as an appropriate label for the communication of best products within Germany. A consortium of research institutions, led by the Öko-Institut, was commissioned by the ministry to develop eco-label criteria for altogether 100 climate-related products. As a methodology, the consortium uses the Product Sustainability Assessment (PROSA): the assessment gives a market overview and an analysis of consumer behavior, products are analyzed technically and best available technologies are identified. Over a life cycle approach particularly relevant effects of the products at production, use and disposal are investigated. The focus of PROSA is not only on the energy consumption but also on other environmental and health aspects and economic impact of the product. Based on this analysis eco-label criteria are derived through a stakeholder process and are proposed as award criteria for the Blue Angel.

Introduction

Climate protection is one of the main challenges of this century. This has been accepted as consensus in society and each individual tries to make a contribution to this effort. But the key energy-saving opportunities are often associated with large financial or habit-related barriers, as e.g. improving the energy performance of buildings or the switch from private motor vehicle to public transport or bicycle. Climate protection therefore requires low-threshold offers to reduce the individual carbon footprint. At his daily purchasing decision the consumer must be enabled to pick the best product in terms of climate protection and to influence the market by his conscious consumption.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) recommends in a memorandum about Product Carbon Footprint the well-established Blue Angel eco-label as an appropriate label for the communication of best products within Germany. Blue Angel is a Type I environmental label according to ISO 14024, the application of the label is voluntary. The development of criteria to be met is based on a life cycle approach. The Blue Angel, known in Germany by 80% of consumers, should be developed to a national climate protection label for products according to the expectation of the ministry. The label therefore was extended by the addition "protecting the climate" and will mark in the future in all major product segments (except food) these products that are particularly energy-efficient or make a particularly large contribution to energy savings. Additionally these products meet requirements on other important environmental characteristics such as harmful substances, recyclability, complying with water conservation and low noise emissions.

The research project Top100

The research institutes Institute for Applied Ecology (Oeko-Institut), Institute for Energy and Environmental Research (IFEU) and the Institute for Environmental Strategies (Ökopol) form a consortium within the project, which, under the National Climate Initiative, is responsible for determining the 100 most climate-relevant products and services (Top100) and for developing eco-label criteria for these. Examples of these products and services are boilers, solar panels, wood fuel, insulation, lamps, televisions, computers, washing machines and dishwashers, refrigerators, freezers, coffee machines and energy services.

The project represents a special case of the application of the PROSA methodology. Based on a market analysis, this particular PROSA includes a simplified life cycle assessment of a representative product, the calculation of typical life cycle costs of the product and an analysis of use of the product group. Along the life cycle of the product, sustainability aspects are investigated, whereby the specific hot-spots of the product are being identified. As a consequence of ambitious requirements, as, for example, on material composition, on energy consumption or the availability of spare parts, a list of criteria is created which can only be met by about 20 percent of the products available on the market.

As basis for the award of the eco-label "Blue Angel", the criteria developed by the consortium, led by the Öko-Institut, following a transparent stakeholder process will finally be submitted to the independent "Environmental Label Jury" for adoption.

The development of award criteria for eco-labels has a major impact which goes far beyond the identification of specific items:

1. The eco-label anticipates legal regulations and tests their applicability in the market. Example: In the late 1970s, "The Blue Angel" to CFC-free spray anticipated the German CFC Halon Prohibition Ordinance.
2. The catalogue of criteria helps to make a choice between "toprunner" products which, in the context of award programs for more energy-efficient products or through information campaigns such as www.topten.eu, for example, can strategically be promoted.
3. The high energy efficiency of eco-label products sets the standard for the development of European eco-design requirements, minimum standards for products that can be marketed in the European Economic Area being defined at EU level.
4. The award criteria of the eco-labels are frequently applied in private and public procurement. In order to serve this market, manufacturers have to develop their products according to the requirements of the label

PROSA Methodology

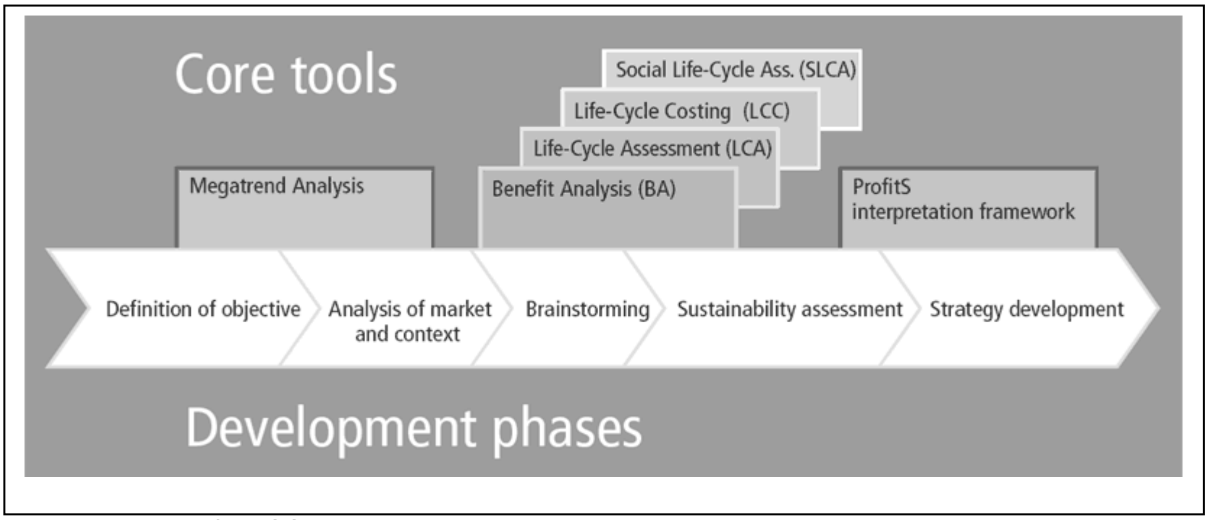
PROSA – Product Sustainability Assessment is the method developed by the Oeko-Institut for a strategic analysis and assessment of product portfolios, products and services [1]. Typical users of this method are companies that like to know more about their product portfolio with regard to sustainability aspects. With these findings, companies can derive appropriate measures to improve their products' environmental, social or economic performance or they may open up promising new and sustainable markets. For the product policy, PROSA is an appropriate method to record the most important impacts of products and services and, for example, to therefrom ensue legal minimum requirements or incentives.

As a sustainability assessment, PROSA not only includes the environmental impacts of a product, as Life Cycle Assessment (LCA) does, but also examines the social and economic impacts. The investigation covers the entire life cycle of the research object from raw materials extraction to disposal.

PROSA is based on existing and well-established core tools and integrates them. The approach is process-oriented and iterative. An interdisciplinary project team actively supports the process and, as the assessment progresses, decides on further investigations. The participation of stakeholders provides an even broader social basis for this process. The following methods are constantly being used:

- Megatrend Analyses
- Life Cycle Assessment (LCA)
- Life Cycle Costing (LCC)
- Social LCA
- Benefit Analysis (based on consumer research)
- ProfitS evaluation tool (Products Fit to Sustainability)

The following chart shows the basic structure of PROSA:



Basic structure of PROSA [1]

Depending on the application, PROSA can be conducted with different goals and intensity. Especially for small and medium-sized enterprises, the Oeko-Institut has developed a simplified screening PROSA method (s-PROSA), which already allows a general orientation of the key sustainability issues. As part of the project Top100 described below, in which awarding criteria for eco-label are developed, Oeko-Institut has adapted the PROSA methodology in such a way that only those aspects are investigated which can currently be regulated by an environmental label.

The role of PROSA in the development of award criteria

For the Top100 project, a simplified screening PROSA method is applied. This is partly attributable to the time and financial constraints of the project, in which many product groups have to be processed in a relatively short period of time. Above, certain problems relating to products cannot be remedied by eco-labels. Social issues, for example, that could be analyzed by the Social LCA, are usually exempted from the investigation, and are only considered in very obvious cases (such as child labour in the manufacture of toys or textiles or working conditions on board of cargo ships).

In accordance with the scheme described above, PROSA within Top 100 aims at the:

- identification of the most relevant product groups (focusing on climate change)
- description of the products and setting of minimum requirements
- derivation of criteria for the award of a voluntary eco-label

As a first step, the market and the surrounding field of the product are investigated:

1. market overview of the product group with prices, price trends, sales figures, typical features, consumer trends and consumer-related issues. In addition to manufacturers' data, information provided by market research companies and internet-based market researches, comparative product tests conducted by neutral consumer magazines are important sources of information,
2. analysis of the legal framework of a product, such as Ecodesign requirements, REACH, tax treatment of the product (e.g. fuels),
3. research of the existing eco- or product labels (e.g. the EU Eco-label, Nordic Swan, Energy Star, TCO) and the underlying criteria,
4. identification of standards and admission requirements relating to the product which have to be met in order to market the product on the European market (European CE standards mark).

In order to

In the Top100 project, the process step "brainstorming" is understood as an interdisciplinary exchange of the people and institutions involved in the product group (manufacturers, laboratories, consumer organizations etc.). Within this step the precise focus, i.e. sustainability assessment, is defined and the product group is limited or extended as required.

The actual sustainability analysis ("Sustainability Assessment") is divided into the following steps:

- Analysis of Benefit and Utility
- Indicative Life-Cycle Assessment (LCA)
- Life-Cycle Costing (LCC)

In the context of PROSA, the analysis of the product benefit (analysis of benefit and utility) is an essential tool. Using checklists, consumer benefit (practical utility), symbolic value (symbolic utility) and social benefits (public value) of a product is investigated. Based on the benefit analysis, action alternatives (such as hiring instead of buying) or product alternatives (e.g. notebook instead of desktop PC) can already be identified.

For the methods LCA and LCC which are subsequently applied, a typical product is defined and assumptions are made about the typical use and lifetime of the product. These assumptions can, for example, be made on the basis of existing product category rules, as they are used in the context of environmental product declarations or under consideration of case studies from the European eco-design process.

For the typical product, an indicative life cycle assessment (LCA) is performed, which at least calculates the cumulative primary energy demand (CED) and the Global Warming Potential (GWP) of manufacture, use and disposal of the product. As household and office appliances have been assessed as part of Top100, it was found that the use of products makes up a significant share in energy consumption over the entire life cycle. The use of a 32-inch LCD TV, for example, contributes with 86% to the total greenhouse gas emissions within the product life cycle [3]. Against this background, for certain household appliances, such as refrigerators and freezers, the early replacement of functional, but inefficient equipment by high-quality, energy-saving devices can make a significant contribution to climate protection.

The analysis of life cycle costs (LCC) makes such an investment decision even easier. In LCC, investment costs, operating costs such as energy and repair costs and possibly disposal costs are calculated down to a year of use. This way, a statement about the actual cost burden of a product can be made. A more expensive but energy-efficient product can result in substantially lower annual costs than a cheap or even free (already paid) product. The results of the LCC, however, can also reveal that certain efficiency measures may be associated with disproportionately high costs (e.g. very high spin speeds in washing machines) and therefore should not be set as minimum standards.

By the individual tools that are used within PROSA, one gets a very differentiated view of the relevant product group and gets to know the different aspects of sustainability with regard to this product group. In the next process step, the award criteria for an eco-label will be formulated.

Typical criteria in this respect are:

- Maximum energy consumption per year for a given usage profile
- Durability
- Usability (minimum functionality, upgradeability, security)
- Maximum noise emissions
- Repairability (design and delivery of spare parts)
- Absence of materials that pose a risk to human health and/or the environment
- Recyclability
- Good consumer information

As already mentioned above, the criteria aim at covering about 20% of the best products available in each product group on the market. This means that none of the criteria must be set too sharply so as to possibly exclude all products or to prefer just one manufacturer.

To ensure this, a compulsory expert consultation takes place as part of the development of the eco-labels under Blue Angel, to which interested parties such as producers, but also environmental and consumer organizations, academia and government agencies are invited. This involvement of stakeholders complies with the PROSA methodology in the process step "Strategy Development", in which the findings one more time have to be subjected to an interdisciplinary discourse. The experts will discuss the proposals on the award criteria and will consider whether they are in principle applicable to their products. Ideally, the criteria are adapted to such an extent that a consensus between the stakeholders will be reached. However, there is no reason to fear that the criteria will be set too weak because of the influence of the manufacturers, as manufacturers only may use an eco-label as a positive distinction feature if their (environmentally friendly) products stand out from those of competitors. If an agreement with the experts cannot be reached, the points at issue are documented.

At the end of the development of a new eco-label under Blue Angel, there is the “Jury Umweltzeichen” ("Environmental Label Jury”). It is composed of representatives of socially relevant groups and is appointed by the Environment Minister. The Jury Umweltzeichen will review the submitted draft again and then adopt it in a democratic process.

From that time, products may bear the label Blue Angels and thus show the consumer which of the products are particularly exemplary in terms of the requested aspects of sustainability. The sign enables the consumer to purchase strategically, and to prefer those companies and products that meet his expectations to a maximum extent.

Status quo and future perspective of climate relevant product groups awarded the Blue Angel

During the pilote phase of the project [4] award criteria for ten product groups were developed: washing machines, tumble dryers, DVD players, and cooling and refrigeration devices, gas cookers, electric kettles, masterslave plug connector strips, netbooks, espresso machines, TV sets. Due to the ongoing Ecodesign process and revision of the EU energy label the award criteria for tumble dryers could not be finished yet. For the other 9 product groups the award criteria can be downloaded at www.blauer-engel.de/en/.

During the currently running Top 100 project for a whole range of products award criteria are under development. In principle the covered product groups belong to the following categories:

1. Energy using products: products that use energy during use, e.g. dish washers. For better clearness these products are again separated in different product categories, like e.g. household appliances, IT equipment, heating & cooling, mobility, lighting. Note: The Blue Angel does not cover products/services in connection to travel & holidays (e.g. hotels).

2. Energy related products: products that do not need energy during the use phase but that influence energy demand of other products/systems, e.g. windows, energy meters, water saving showerheads. Note: The Blue Angel does not cover food products.

3. Climate relevant product groups: products that are neither covered in category 1 or 2, but that are climate relevant due to relevant impacts during production, like e.g. paper.

The subsequent table gives an overview for which product groups award criteria have already been developed (left column) and those who are currently under development (right column).

Status quo of the Basic Criteria for award of the Environmental Label developed within the project Top 100

Award criteria published on www.blauer-engel.de/en/	Award criteria currently under development
Energy meter, Electric ovens, Photovoltaic products, Dish washers, Microwave ovens, Household cooker hoods, Domestic lighting (Compact fluorescent lamps and LED lamps), Computers (desktop PCs, nettops, notebooks), Thin clients, VoIP telephones, Compact hi-fi systems, Wood pellets, Woodchips, Eco-Friendly Ship Design	E-book readers, Green data centres, Water saving showerheads, Routers, Energy contracting, Electric cookers, Vacuum cleaners, Coffee machines (filter drip and pad machines), windows, photovoltaic panels, office lighting (linear fluorescent lamps, LED lamps, dimmable ballasts), street lighting, air conditioning, elevators, photovoltaic power inverter, rail cars, bicycles, external harddisks, bell transformer and talk back systems, steamer, daylight guidance systems, light control, lithium batteries, tumble dryers

Further product groups will be defined in the course of the project. Until 2012 award criteria for overall 100 product groups will be developed and that way support the establishing of the Blue Angel as the national Label for Climate Protection in Germany.

References

[1] Grießhammer, R.; Buchert, M.; Gensch, C.-O.; Hochfeld, C.; Manhart, A.; Rüdenauer, I.; in collaboration with Ebinger, F.: *Produkt Nachhaltigkeits-Analyse (PROSA) – Methodenentwicklung und Diffusion [Product Sustainability Assessment (PROSA/PLA) – Methodology development and dissemination*] Oeko-Institut Freiburg/Darmstadt/Berlin. 2007

[2] Grießhammer, R.; Hochfeld, C.: *Memorandum Product Carbon Footprint. Position statement on measurement and communication of the product carbon footprint for international standardization and harmonization purposes.* Oeko-Institut, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and Federal Environment Agency (UBA). Berlin. 2009.

[3] Zangl, S.; Brommer, E.; Grießhammer, R.; Gröger, J.: *PROSA Fernsehgeräte – Entwicklung der Vergabekriterien für ein klimaschutzbezogenes Umweltzeichen [PROSA TV sets – Developing the award criteria for a climate label].* Oeko-Institut. Freiburg. 2009

[4] Grießhammer, R.; Bleher, D.; Brommer, E.; Bunke, D.; Gensch, C.-O.; Graulich, K.; Grether, S.; Gröger, J.; Lüders, B.; Möller, M.; Prakash, S.; Quack, D.; Schmied, M.; Schüler, D.; Stratmann, B.; Zangl, S.; in collaboration with Bush, E.: *Umweltzeichen für klimarelevante Produkte und Dienstleistungen [Ecolabel for climate-relevant products and services]*. ; Öko-Institut e.V. in cooperation with Bush Energie GmbH; 2009

Topten: Global Project for the Most Energy Efficient Products

Eric Bush, Sophie Attali, Conrad U. Brunner, Norman Dean, Anne Arquit Niederberger, Hu Bo

Topten International Group TIG, Paris, France, www.topten.info

Abstract

Topten is an international program to create a dynamic benchmark for the most energy efficient products [1-11]. An important step was the expansion to China and USA in 2010. This paper highlights the impact and trends of Topten and its achievements and current challenges:

- Increasing number of product categories: Topten currently presents the best products in a wide range of categories such as cold appliances, washing machines, clothes driers, coffee machines, lamps, office equipment, TVs, and air conditioners. Topten continues to expand the types of products it evaluates.

- Globalization: Topten is, in part, a response to the global appliance market. As well as the suppliers, Topten has to be globally active to have influence on markets and global consumer buying behaviour. This confers a new dimension to the originally European program and permits an exchange of information between the continents.

- Best Available Technology (BAT)-Reference: www.topten.info is a reliable BAT-reference and resource for best available technology values. It sets product efficiency benchmarks, presents the very best products sold in Europe (www.topten.eu), and offers policy recommendations. Thus it is an important tool for policy design processes, such as the EU Eco-Design Directive for Energy-related Products, EU Labelling Directives, Energy Star and national product policies.

- With its short cycle for reviewing and updating benchmarks and the ability to continuously add new products entering the market to Topten listings – in contrast to labels, political instruments and governmental/public bodies – Topten can react immediately to the development of more efficient technologies to provide the up-to-date information that consumers and policymakers demand.

Introduction

Topten is coordinated by TIG, the Topten International Group. Main partners and funders of Topten are the European Commission (SAVE projects), WWF, the European Climate Foundation, the Swiss Government (SECO and REPIC) and many national funders. Topten is a transparent system to continuously identify the “best” products available in each product category (with energy efficiency a key criterion) and to make the results freely accessible via a user-friendly Internet interface (www.topten.info). Topten is a comprehensive platform for energy efficiency: Manufacturers, retailers, large scale buyers and public procurement officials as well as consumers can benefit from the online lists of the most efficient products, the experience and partnerships built by Topten programs, and the information and advice provided to policy makers and end-users.

In Europe, the use of electrical appliances has a major impact as household electricity consumption represents over 30% of total electricity consumption[1]. Therefore the potential to reduce energy consumption and associated carbon emissions through the use of highly energy efficient appliances is significant.

The market for these energy-using products is a complex one, generating three main difficulties:

- For consumers: With an increasing number of energy-using equipment present in our homes

[1] Energy efficient products, Consume Green, 22 project funded by the Intelligent Energy Europe programme, Report n°3, July 2008.

and workplaces, and a wide variety of brands and models available on the market, consumers find it difficult to chose the best performing products and are influenced by many other, often conflicting, messages in their purchasing decisions.
- For manufacturers: The development of energy efficient and innovative products has an initial cost. Manufacturers rely on market demand for these efficient products in order to start their production and to develop genuine marketing strategies.
- For policy makers and regulators: Under the pressure of budget restrictions, it is not always easy to implement ambitious and successful policies, despite the shared concern about climate change and energy issues.

.

The purpose of Topten is to provide consumers and energy-management professionals with credible, up-to-date information on the most efficient products available on their local markets. Information on specific product categories is displayed on national websites, in a consumer-oriented way, using pictures, describing functions, availability, listing prices and comparing total costs (purchasing price plus energy and water costs over the life time) with that of a non recommended model – however also available on the market. Because only the best-performing products are listed, the selection is much narrower than typical labeling systems, making it easier for consumers to choose from among the thousands of products available. The selection is based on existing regulations and international energy measurement standards[2], but no complex calculations are involved for visitors of the website: they access best products in one click.

This Topten information covers energy using products of interest for individual consumers and for large buyers (depending on countries): cold appliances (refrigerators and freezers), wet appliances (dishwashers and washing machines), tumble driers, air conditioners, TVs, efficient lighting (CFL and LED), computer monitors, ink jet and laser printers, copiers and multifunction devices, cars, coffee machines, vacuum cleaners, pumps.

Topten is neutral, rigorous and transparent in that there is no influence from manufacturers or retailers and the selection methodology is explained online. Advice for proper use of appliance and equipment is also accessible on-line.

But the Topten concept goes far beyond simply providing web-based information. The websites are actually only the "visible part of the iceberg" and rely on three main pillars:

- Daily technical work on products, in collaboration with manufacturers and importers in order to identify best available products and check all information published and keep it up-to-date,
- Daily media work to attract a large number of visitors to the websites, demonstrating there is an strong interest for high efficiency products,
- Partnership developments with multipliers aiming at specific target groups: retailers, public procurers, local governments, environmental and consumer NGOs, utilities, etc.

Objectives and impacts

The over-all goal of Topten is to stimulate market transformation towards more energy efficient products and to contribute against climate change. Topten pursues three specific objectives, to:

- Increase consumer demand for high efficiency products and awareness on their benefits,
- Increase the availability of high efficiency products across the market and therefore stimulate continual product innovation to drive product performance improvement as rapidly as possible
- Increase the professional demand for high efficiency products and knowledge about their benefits.

Through these objectives, Topten will make a number of direct and indirect contributions to fulfilling CO2 and energy demand reduction targets by reducing the energy consumption of energy using products, which make up 30% of total energy consumption.

---

[2] European Energy label, EuP implementing measures, Energy Star, European Eco label, Blue Angel…

Within the market transformation toolbox, Topten is considered as a "soft measure" which focuses on the cutting edge of the market, pulling the whole market toward more energy efficiency. It has several impacts on the market (Bush et al., 2009) by supporting:

- Consumers with targeted information
- Manufacturers in the promotion of their most energy efficient products
- Retailers in increasing their mark-up and reinforcing their image
- Large-scale buyers and public procurement officers in choosing efficient products
- Policy makers with the identification of best available technologies
- The media, acting as a trustable and independent source of information
- NGOs, institutions and utilities, using Topten in their daily work

Topten has in several product categories (e.g. laundry driers, coffee machines etc.) proven to be able to move market transformation towards more efficient products swiftly. Its independence from direct industry influence has given credibility to influencing government standards and labels.

Key results of Topten Europe

The European market continues to be surprisingly fragmented among individual national markets or at least regional markets (e.g. regional markets like Scandinavian countries, southern European countries etc.). Even though only a few major industrial companies produce appliances and distribute them across Europe, they do not deliver high efficiency products evenly. For example, a Topten.info[3] research covering 23 countries shows that in May 2009 there were 286 A++ cold appliances across the entire European market. However, out of these 110 different models were available in Germany compared to only 1 in countries such as Spain, Greece or Norway.

Even though the context is very internationalized, national markets continue to be influenced greatly by different patterns of use (for instance laundry washing/drying in Scandinavia versus southern Europe), different tax regimes and energy costs, and also the different languages. The differences in GDP, in consumption and energy intensity between new and old Member States and also within new Member States can also be remarkable, e.g. in Romania where the primary energy intensity is 3,9 times higher than the EU 27 average[4] and where the Electricity consumption per dwelling is about 1750 kWh in the urban area and about 850 kWh[5] in the rural area.

In concrete terms, this means that most products in Europe:

- Differ technically between member countries or regional country groups, and that only few products are uniform across Europe (cars, Office Equipment, some Consumer Electronics for instance),
- Bear different brand names even where they are technically identical,
- Have different prices (due to different marketing strategies, different rates of value-added tax and due to special features of national and regional markets) and also
- Have significantly different life-cycle costs due to different energy and water prices.

The outcome of this situation is that manufacturers are unable to make use of potentially cost-saving economies of scale, and retailers and large consumers face extra cost and increased information-gathering effort. For private consumers, this situation means that an orientation to nationally available products continues to prevail and European-level harmonization is difficult to achieve. Consumers also lose out in terms of access to the best performing products, as these are not distributed evenly across the EU market.

[3] Source: Topten.eu, cold appliances, market situation.

[4] In 2007, using Euro2000, source: Eurostat

[5] In 2007, source: Romanian Institute of Statistics data processing

Given this situation, Topten offers a number of strengths in its approach by working both:

- Close to the consumer, at national level, providing information on the products actually available on national markets as a Portuguese consumer does not care for high efficiency products available in Poland and match the preferences of Polish consumers.
- Close to the manufacturers, at international level, where strategic decisions are taken: 18 European countries are working in parallel with their own Topten website (within the "Euro-Topten-Max" SAVE project) reaching a critical mass and being heard as a single voice spreading the message in favour of energy efficiency.

Providing clear information to different target groups and having a dialogue with manufacturers' headquarters is particularly important at a time when new regulations are being enforced (ErP implementing measures, new labels and new product labelled). Topten actually contributes to the Eco-Design and labelling processes and therefore to the EU 2020 targets: Topten offers the opportunity to provide a realistic overview of the availability on the EU internal market if energy efficient products, to stimulate the diffusion of the most innovative products and to support decision makers to launch new initiatives promoting products efficiency and energy conservation. The Topten information, be it at national or European level, is often used by the European Commission as a reference and benchmark for future policy design, labelling strategies, dissemination programmes, as a basis for the adoption of minimal efficiency requirements and specifications for large-scale buyers.

Key figures of Topten Europe:

- 188 product categories were displayed on-line
- Broken down into 409 subcategories (presenting the most appropriate market segmentation from the consumer point of view)
- More than 11 100 products were listed. This represents only the small share of the most energy efficient products available in the corresponding countries, products which were identified and for which the Topten teams have led a paper check in collaboration with manufacturers
- More than 1 million visitors between January and May 2010 (generating 13 million hits)
- From January 2009 to June 2010: More than 28 000 articles in the printed media generating 95 Million readers, more than 2 000 Internet articles generating more than 20 million hits, more than 100 television reports with 74 million viewers and more than 200 radio reports with 31million listeners
- More than 40 partnerships with organisations relaying the Topten message in their daily activities (e.g. cities, utilities, NGOs, retailers).

At the international level, Topten China and Topten USA were launched in October 2010. Beyond the usefulness for local consumers and global climate action, this is a crucial development for Europe because it will allow a better understanding of energy using products that are massively imported to the European continent.

Key results of Topten China

China is in a rapid phase of economic development not only in urban areas. Millions of households have now access to refrigerators, room air conditioners, TVs and motor vehicles, etc. The rural market is also keeping expanding due to incentive policies such as “Home Appliances Going to the Countryside”, etc. Energy consumption and greenhouse gas emissions due to the use of consumer goods are growing rapidly. Because coal plays the fundamental role in China’s electricity generation, improved energy efficiency for consumer goods in China is a key element in Chinese energy policy in order to slow up the need for additional electric generating capacity and greenhouse gas emissions.

Topten China provides the internet platform www.top10.cn to show the most energy efficient products among household appliances, consumer electronics, office equipment, building components (including solar), and motor vehicles. The Topten products use on average only 60% of the energy of a similar standard product sold, in many cases they use only 30% of the existing old product being replaced. The Topten information platform serves to stimulate consumers to buy energy efficient products and to help retail chains and manufacturers to bring more efficient products onto the market.

On 26 October 2010, www.top10.cn was publicly launched in Chinese (simplified Mandarin) and English with 7 product categories listing 259 products: refrigerators, washing machines, electrical water heaters, air conditioners (fixed speed and inverter), monitors, copiers and passenger cars. The expansion in 2011 will include several additional key product categories (e.g. TVs, lamps, microwave ovens).

Figure: Screen shot entry page of Topten China

Chinese page	**English page**
	

Figure: Chinese and English product pages: air conditioners

The Topten products are selected based on market research in key retail stores in China and from public available government databases. Their selection into the Topten list also depends on the accuracy of the energy performance data. Mostly manufacturers' self-declared data according to the standards and energy labeling and certification scheme are currently available. Check testing has proven that these data are not always sufficient and sometimes grossly inaccurate to select the very best products according to Chinese testing standards and the China Energy label criteria.

Conformity test program

The declarations given on energy labels (e.g. in China, USA, Europe) usually are provided by the manufacturers. In order to secure the energy performance data of the selected products, a first round of conformity tests with the following products was made by China Household Electric Appliances Research Institute:

- Refrigerator/freezers
- Air conditioners
- Monitors

CHEARI CTP	Total products	Passed products	Failed products	Passed (%)
Air conditioner	9	8	1	89
Refrigerator	10	9	1	90
Monitor	10	10	0	100
Total	29	27	2	93

The conformity test of 29 products showed that two did not comply and various smaller deviations of self-declared values were revealed. Most of the products (93%) meet the requirements set by Chinese standards and regulations. The measured energy performance of the air conditioners and refrigerators usually are lower than the declared performance from the manufacturers. The measured energy performance of monitors is higher than the declared performance from the manufacturers.

Media work and public launch

The public launch was a coordinated international event with Topten China, and Topten USA to demonstrate the global reach of the energy efficiency platform. It was the successful test of the build-up of a media network with several key media partners: Currently we are in contact with 14 media in China. Among them, the most important ones are:

- Sina (one of the biggest portal websites in China)
- Autohome (one of the most popular car websites)
- PCPOP (one of the most popular IT products websites)
- China television CCTV (a WWF media partner, to be pursued further)

The media echo of the launch in China was very big: The following print and electronic media brought a report on Topten China: Beijing times, Fazhi news, China environment news, Sina Green, Sina news, PCPOP, IT168, CHE168, Autohome, Tianjin news, China5e, 163, qq, YNET, Sohu, WWF websites around the globe, VECC website.

Government relations and partners

Government activities in this field are highly relevant in China. They include:

1. Testing standards
2. Mandatory energy minimum performance standards (MEPS)
3. Financial incentive programs
4. Procurement lists

Chinese government agencies (SAC, AQSIQ, CNIS, VECC, ERI, et cetera) are interested and open to international exchange on several energy efficiency matters which Topten could support: standards, labels, procurement, financial incentives, testing.

Lessons learned

The experience of building up a test site (by end of 2009) and making a public launch of 7 key product categories with 259 products in October 2010 has provided some key insights into the Chinese decision making and market transformation potential of consumer goods:

1. Basically the innovative approach of Topten was – after a time of hesitance – accepted and appreciated. The hesitance was due to the competition of BAT products (maybe 5% – 10% of the market) with the energy labeled products in the best China "Class 1" which often include between 30% and 80% of all available products.
2. The fear was also that Topten would often select only high performance foreign brands (Electrolux, Siemens, Bosch, Toshiba, Panasonic, Osram, Philips, et al), neglect Chinese brands and thus cater for a high priced premium product and consumer segment only. However, the test site already showed by the end of 2009 and now the published site proves that this is not the case and that there are many Chinese brands at acceptable prices that can compete easily with imported foreign brands. Only 42% of the 259 products have foreign manufacturers from Japan, Korea, Europe, and USA
3. An Advisory Group (AG) was created as part of an effort to form a Topten China Framework agreement that includes a number of key organizations in China contributing to the significance of the approach. The AG has a Charter with an informal status. Initially, some high officials contacted saw a potential conflict of interest in their government role and supporting an NGO selection of BAT products, while they appreciated Topten's efforts contributing to the Chinese government's national policy "Save the energy and reduce the emission". The AG makes Topten China working close to the high priority fields of energy and climate.
4. The first pilot set of conformity testing has shown that it needs to be repeated systematically for most of the product categories to secure the accuracy of the energy efficiency data.
5. Market research of energy efficient consumer goods in China confirms experiences of other regions:

    - The testing standards are sometimes outdated and not internationally harmonized, not able to distinguish performance with new advance technology (e.g. quality of compact fluorescent lamps).
    - The government minimum energy performance standards MEPS are decided on late and too low, and sometimes they are not fully enforced.
    - Some financial incentives have been implemented (ACs, motors) and mostly oriented towards increasing sales volume, not top class energy efficiency.
    - Procurement lists are too long and include cheap low quality products as well as energy efficient products.

6. We have learned that the key element in the process of market transformation is to make the access for better products faster and easier. China has already a set of energy efficient products but they are not easy to find and not available in all retail stores.

Key results of TopTen USA

TopTen USA, was formed as a U.S. nonprofit organization in early 2009 by a group of U.S. environmental organizations, national and regional energy efficiency groups and utilities (see Bush et al., 2009 for a brief history and Dean, Bauer & Coakley 2010 for an update). The organization's startup was funded by charitable contributions and significant in-kind donations of time by the staffs of the founding groups. TopTen hired its Executive Director in August 2009 and, working through a team of expert consultants, developed its initial product lists and built a state-of-the-art web site. See www.toptenusa.org. The web site was beta tested through the summer of 2010 and opened to the public on November 9, 2010.

TopTen USA launched with lists of 10 product categories, some of which have been subcategorized. Table I lists the product lists currently found on the TopTen USA web site, those expected to be completed within the next two months, and the schedule for product category revisions.

Product Category	Subcategories	Revision Schedule
Refrigerators	Extra-large Large Medium	Annually
Freezers	none	Annually
Televisions	Large Medium Small	Every four months
Laptop Computers	none	Every four months
Desktop Computers	Expandable Non-expandable (under development)	Every four months
Cars	none	Annually
Light Trucks & SUVs	none	Annually
Dishwashers	none	Annually
Clothes Washers	Large Small	Annually
Computer Monitors	Large Small	Annually
Room Air Conditioners (completed, to be available when retailers begin to sell machines)		Annually
Water Heaters (to be completed in June 2011)	Condensing Gas Storage Condensing Gas Tankless Heat Pump Storage (tentative subcategories)	Annually

In general, as noted in the Table, TopTen USA will revise electronic products every four months and white goods and vehicles annually. However, it will add products to its top ten lists between specification revisions if new products enter the market that are more efficient than the currently listed products.

Once a product is on the TopTen list, it will remain on the web site for a period of at least six months after it has been "bumped" from the top 10 list by a more efficient product. In such cases, the older listed products will be moved onto a separate list for a period of six months (or until they are no longer sold, whichever comes first) and will be "vintaged." Vintaged products will bear the date on which they were first listed and can continue to be marketed as "TopTen listed" products.

The potential energy and cost savings from the TopTen USA program are substantial as shown in the estimates in the Table.

PRODUCTS	Energy Use of Typical Old Appliance (kWh/year)	Cost to Run Typical Old Appliance ($/year)*	Energy Use of an Energy Star-Qualified Appliance (kWh/year)	Cost to Run Energy Star-Qualified Appliance($/year)*	Energy Use of Leading Same-Sized TopTen Appliance (kWh/year)	Cost to Run Leading Same-Sized TopTen Appliance ($/year)*	CO2 Savings Over Life of Product if All Products Were TopTen instead of Old (Metric Tons)	Electricity Cost Savings Over Product Life if all Products Were TopTen instead of Old ($/lifetime)
Large LCD Televisions	455	$54.60	243	$29.16	81	$9.72	88,825,361	$ 15,259,200,000
Computers	231	$27.72	55	$6.60	22	$2.62	61,375,838	$ 10,543,680,000
Clothes Washers	790	$94.80	381	$45.72	118	$14.16	45,136,659	$ 7,753,971,456
Refrigerators	1,065	$127.80	590	$70.80	356	$42.72	59,812,672	$ 10,275,145,632
Freezers	674	$80.88	704	$84.48	460	$55.20	3,451,414	$ 592,914,221
Dishwashers	451	$54.12	324	$38.88	180	$21.60	14,771,299	$ 2,537,543,405
TOTALS	3,666	$439.92	2,297	$275.64	1,217	$146.02	273,373,243	$ 46,962,454,714

Table: TopTen USA CO2 and money saving estimates thanks to the use of TopTen appliances

Even when compared with ENERGY STAR qualified products, energy savings of at least 40% are possible by deploying TopTen-listed products, and many categories would deliver larger savings (over 65% for the large TVs and freezers). The cumulative carbon dioxide emissions reductions estimated for the electrical products listed in the table are equivalent to over one-fifth of total US energy-related carbon-dioxide equivalent emissions from the residential sector in 2009 (1.16 billion metric tons CO_2e)[6].

To promote its lists TopTen USA , includes the following features in its program, in addition to energy use and savings:

- Detailed product specifications
- Ties to social networking sites such as Facebook and Twitter.
- Use of blogs and traditional media to publicize the program.
- Current price and availability data for listed products.
- Up-to-date information on any financial rebates available for listed products and direct links to instructions on how to claim the rebates.

The TopTen USA website also contains educational material for consumers on how to buy, use and properly dispose of or recycle products.

In order to reach large numbers of consumers, TopTen USA is focusing on four strategies.

First, TopTen is building “partnerships” with non-governmental organizations having large memberships. Those organizations are linking to our web site and encouraging their members to visit our site and buy listed products. As of mid-December 2010, TopTen USA had partnerships with organizations having over 3.5 million members. A large U.S. NGO, Environment America and its 26 state affiliates have partnered with TopTen USA to promote high efficiency products. Each of those groups has it own home page. For an example see http://www.toptenusa.org/environmentcalifornia.

Second, TopTen is developing pilot projects with utilities and retailers to reward those that sell TopTen USA listed products. This program is in its infancy and began with the development of a compelling “business” case for utilities to use TopTen to promote more efficient products.

Third, TopTen is working to increase its ranking on search engines. The organization’s approach includes

- Encouraging companies, bloggers, news media and others to link to our site,
- Employing the various tools such as keyword placement that helps with search engine optimization.
- Employing Google Analytics, Alexa and other tools to monitor closely how visitors are using our site and what such data tells us about how to improve the site and site traffic.

Fourth, TopTen USA has begun to run advertisements on Google as the result of a grant from Google. These ads provide consumers who, for example, are searching for high efficiency refrigerators to get a direct link to TopTen’s list of the most efficient refrigerators.

To enable consumers to see top ten lists while in stores, TopTen has a smartphone version of its web site that makes its lists easily read on iPhones, Androids, Blackberry and most other phones with web access. When a consumer attempts to access TopTen USA from a smartphone, the smartphone version is automatically fed to the device.

What does TopTen USA plan in 2011? Among other things, the organization will add an additional three new product categories, improve the functionality of the website-- including adding several new features, and create the ability to feed content out to utility partners and other websites through either a widget or API. It will be expanding its partnerships with utilities, retailers and NGOs

[6] Source: http://www.eia.doe.gov/forecasts/aeo/index.cfm

Conclusions

The expansion of the Topten family beyond Europe is adding value to our collective efforts to stimulate market transformation towards more energy efficient products and thereby mitigate climate change. Benefits of this geographical expansion include:

- Creation of an avid network of Topten management, product and communications experts – as well as partner institutions – around the world who “speak the same language”, which presents greater opportunities to share best practices, technical data, insights, and contact networks.

- Improved understanding of the status and dynamics of global consumer product markets and related product policy developments.

- Greater clout with manufacturers, energy efficiency program administrators and large buyers, due to growing coverage of consumer product markets globally.

- A growing body of experience and lessons learned in a wide range of national contexts to effectively assist additional markets with launching Topten systems expeditiously. We now have a good understanding of Topten success factors; typical budgets and work plans; product data and human resource pre-requisites; effective institutional arrangements; approaches to establish and update project lists, perform quality assurance and assess program impacts.

- Stronger arguments to potential funders and implementation partners, which may seek to invest in impactful and cost-effective programs around the globe. In addition to the above reasons, this includes the potential to pool human and financial resources among TIG members.

A common challenge for Topten systems in many countries is defending the legitimacy and suitability of Topten as a service provider to be the resource of choice to help market actors identify the most efficient consumer products. Governments are sometimes concerned about interfacing with non-governmental actors and may even consider playing this market function themselves. This past fall, the US Environmental Protection Agency and Department of Energy conducted a public consultation on a proposal to create an ENERGY STAR “Top Tier” program, which shares some features common to TopTen USA, but which met with mixed reviews[7]. Whereas there was broad recognition of the need to assist consumers in identifying the most efficient products, some expressed concerns about diluting the ENERGY STAR brand and confusing consumers, as well as whether ENERGY STAR has the resources for a successful and nimble Top Tier initiative (without diverting funds from the core ENERGY STAR program). A number of respondents specifically recommended coordination with existing programs in this general space, including TopTen USA. In Europe, where some Topten systems have been in place for over a decade, the dynamic Topten benchmarking system has proven to be a valuable complement to standard and label schemes.

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission’s Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in two more European countries (www.topten.eu).

- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.

[7] http://www.energystar.gov/index.cfm?c=partners.top_tier_proposal

- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation - www.repic.ch) and SECO (State Secretariat for Economic Affairs - www.seco.admin.ch) who supports the build-up of Topten China

References

[1] Euro-Topten Coordination Team. *Click your way to energy savings - Find out the most efficient products in Europe with a simple click on Euro-Topten websites*. Report 2009. Can be ordered from www.topten.info

[2] Attali Sophie, Bush Eric, Norman L. Dean, Hu Bo. *Topten - Topten Europe, USA and China Reaching a critical mass to face the global appliance market.* Proceedings of the eceee Summer Study. 2011. Can be ordered from www.eceee.org.

[3] Bush Eric, Anne Arquit Niederberger, Sophie Attali, Conrad U. Brunner, Cao Qiaohong. *Topten.info: Market Pull for High Efficiency Products*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Berlin. 2009

[4] Michel Anette, Eric Bush, Jürg Nipkow, Conrad U. Brunner, Hu Bo. *Energy Efficient Air conditioners – Best Available Technology (BAT)*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[5] Attali Sophie, Eric Bush, Anette Michel. *Factors influencing the penetration of energy efficient appliances into national markets in Europe*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[6] Geilinger Eva, Stefan Gasser, Eric Bush. *Testing and rating of domestic luminaires – experiences from Switzerland*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[7] Josephy Barbara, Eric Bush, Jürg Nipkow, Adelmo Pilone. *Super Efficient Coffee Machines – Best Available Technology (BAT) and Market Transformation*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[8] Josephy Barbara, Eric Bush, Jürg Nipkow, Sophie Attali. *Washing machines: Key Criteria for Best Available Technology BAT*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[9] Josephy Barbara, Eric Bush, Jürg Nipkow, Chris Granda. *Energy-efficient heat pump dryers – European experiences and efforts in the U.S. and Canada*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, Copenhagen. 2011

[10] www.topten.info - International platform for best products

[11] www.topten.eu – Best Products of Europe

The 55% tax reductions for building retrofitting in Italy: the results of the ENEA's four years activities

Giampaolo Valentini, Patrizia Pistochini

ENEA, Italian National Agency for New technology, Energy and the Sustainable Economic Development

Abstract

The tax deductions of 55%, in force since January 2007, represents the most generous system of incentives ever established by the Government to promote energy efficiency and sustainable economic development in the Italian real estate system. By the Finance Act 2007 and the subsequent implementation all efforts were addressed to limit the energy consumption during winter heating period.

The results have been successful. Since 2007, 106,000 requests for deduction have been submitted. In the following years the public acceptance for this type of incentives has been further confirmed and strengthened. In late 2008, about 248,000 people had taken advantage of deductions. In 2009 the situation stabilized with 238,000 interventions, confirming the validity of the measure and the users' satisfaction. In 2010, finally, the expectations have been achieved at the same levels of the previous years.

During the first three years about 8 billion € spent by taxpayers, over 4,400 GWh of energy saved per year, roughly one million tons of CO_2 emissions avoided. The validity of the incentives has been extended until the end of December 2011. The ENEA working group, appointed to manage the incentives, has supported the its renewal as represents benefits for the citizens and for the government in terms of tax return, energy saved and employment.

The results

The tax deductions of 55%[1], in force since January 2007 represents the most generous system of incentives ever established by the Government to promote energy efficiency and sustainable economic development in the Italian real estate system. By the Finance Act 2007 and the subsequent implementation[2], all efforts were addressed to reduce energy waste by allowing specific works including: the overall redevelopment of buildings and installation of new biomass boilers, the insulation of horizontal and vertical walls, replacement of windows and entrance doors, installation of thermal solar panels, replacement of heating systems with condensating furnaces or high efficiency heat pumps. All these measures have been established to limit the energy consumption during the winter heating period.

The results have been successful. After a period of several months during which users facing with such generosity felt incredulous, since autumn 2007, the requests for deductions – referred to implemented efficiency measures - are literally taken off, reaching 106,000 units only in the last quarter of the year.

In 2008 the public acceptance for this type of incentive was further confirmed and strengthened. At the end of the year, about 248,000 people took advantage of deductions. The relevant number of requests surprised even the Ministry of Economy and Finance, who, getting worried about the lost revenue that was taking shape, was considering stopping the incentives. That initiative was rejected

---

[1] The system allows for the tax cuts on personal income tax (income tax) and tax on corporate income tax (IRES) for end-users carrying out energy saving measures for winter heating in existing buildings

[2] All legislation and information are available at http://efficienzaenergetica.acs.enea.it

immediately after loud protests by all stakeholders and especially by people who had already taken action.

Other numbers referring to the first three years are relevant. About 8 billion € spent by taxpayers, over 4,400 GWh of energy saved per year, roughly one million tons of CO_2 emissions avoided. The incentives were planned to stay in force until the end of December 2010. The validity of the incentives has been extended until the end of December 2011. The ENEA working group, appointed to manage the incentives, has supported the renewal as represents benefits for the citizens and for the government in terms of tax return, energy saved and employment. A special section in the ENEA web site is dedicated for the management of the 55% tax deduction [1]

The situation has stabilized - still at high levels - in 2009: 238,000 interventions, confirming the validity of the measure and the satisfaction of citizens. In 2010, finally, the trend has not changed: more than 180,000 works ended in mid-December, exceeding the quota reached at the same date in the previous years. A further spike in demand is expected in vision of the work done in the last part of the year, especially considering the uncertainty of the extension of the deductions beyond December 2011. That fear forced many users to anticipate the renovations planned for the current and the following years, in order not to miss the given opportunity.

The results up to now have been very flattering and probably well beyond the expectations of the Ministery: about 800,000 people have taken advantage of them until mid-December 2010, proving an unforeseen success. In this regard, it also acknowledges the results achieved by the ENEA Working Group "Energy Efficiency" that relying only on very few human resources, has proved its competence and engagement to spread information and advice to the public and professionals[3].

A closer look at Figure 1 shows in detail the results of the number of interventions realized in 2007-2009. Data related to 2010 are not yet available, but are not expected to be qualitatively very different from the previous ones. After a slight growth in 2008, when they doubled compared to 2007, in 2009 the number of interventions has remained nearly unchanged. In 2010 we might estimate an increase by 71,3%. The total of the realized works could amount to 1 million.

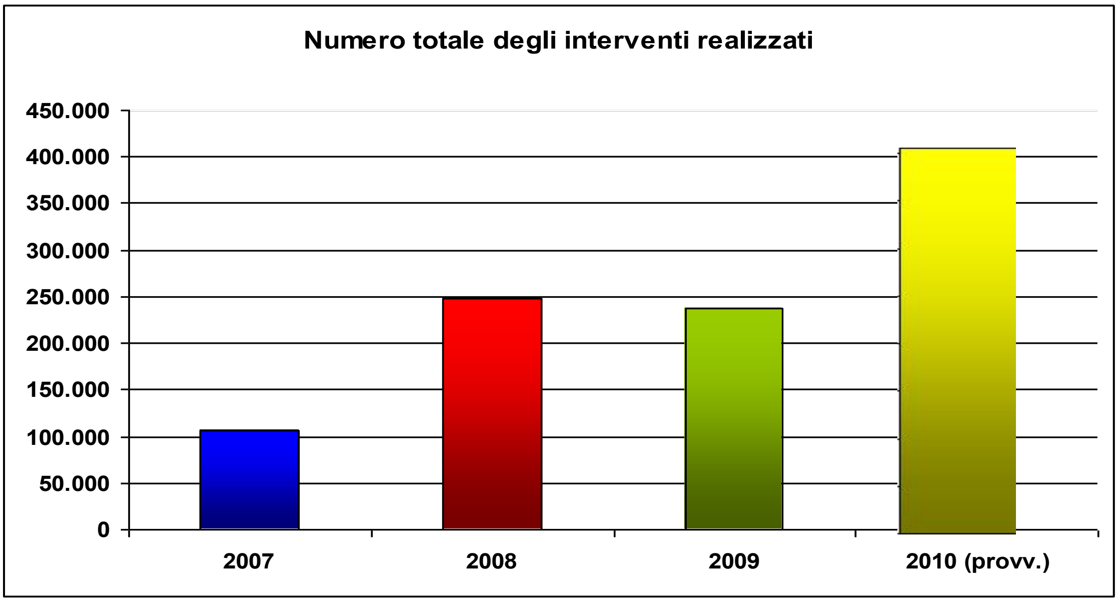


Figure 1 – Number of realized interventions per year (2010 estimated)

[3] This work is still going on by the link "Contact Us" in the mentioned site, through various forms: consulting via e-mail and by phone, interventions in courses, seminars, conferences and in trade fairs.

Similarly, the graph in Figure 2 shows the total cost incurred during the four years of operations. The trend is obviously similar to the previous one. 2008 was characterized by an increase in work still more than double compared to 2007. The costs referred to 2009 show a slight decrease compared to 2008.

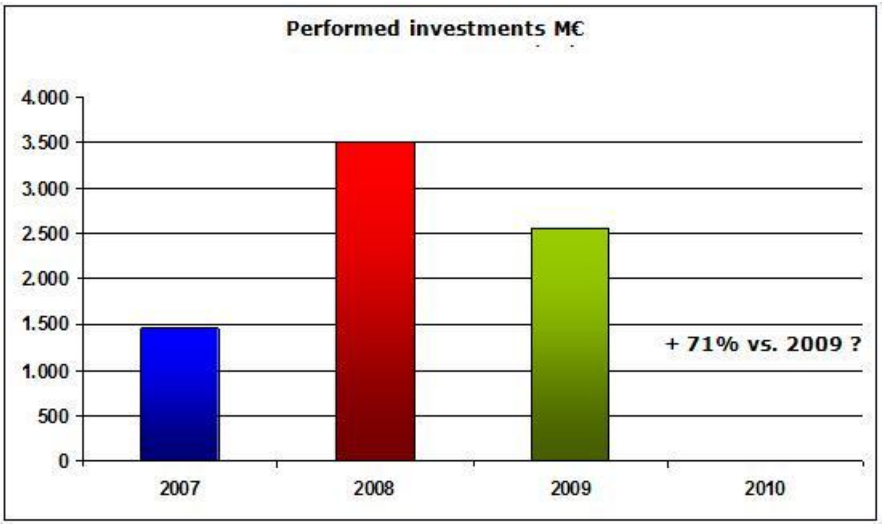
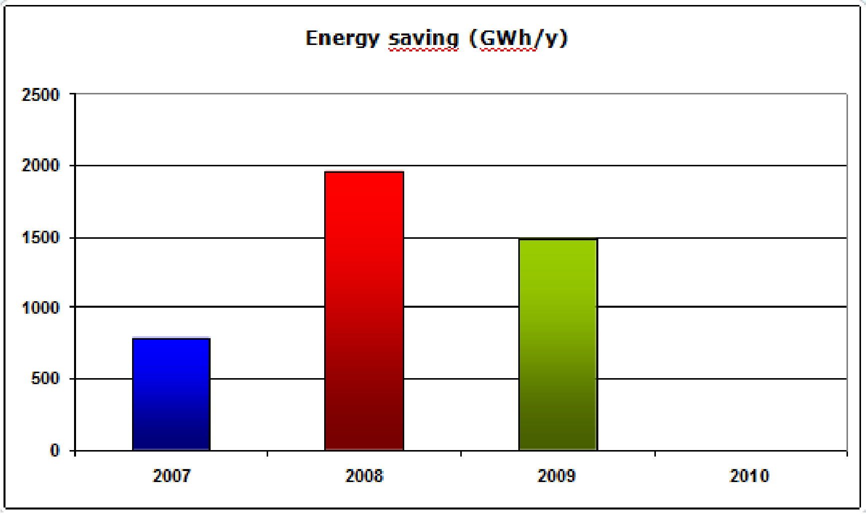


Figure 2 – Investments supported per year (2010 estimated)

Figure 3 describes the results of operations made in terms of energy savings achieved; cost savings have increased from 787 GWh in 2007, to nearly 2000 GWh in 2008 and about 1700 GWh in 2009. According to AEEG (Italian Authority foe Electric Power and Gas), 1 toe saved can be valorized in about 350 €. and, consequently, 1 GWht =>30,000 €. So energy saving can be valorized in 23.6 M€ for 2007, 58.8 M€ for 2008 and 44.6 M€ (final datum) for 2009.



CO_2 not emitted: 2007: 167.400 t/a; 2008: 418.000 t/a; *2009: 317.000 t/a*

Figure 3 – Energy savings per year (2010 non available)

Figure 4 shows the distribution of the requests sent in by regions and referring to interventions subject to tax break in 2008. The most virtuous region in terms of number of tax deduction requests was

Lombardy, Veneto, Piemont and Emilia Romagna come equal third. The Molise region and more generally the South have a rather marginal position.

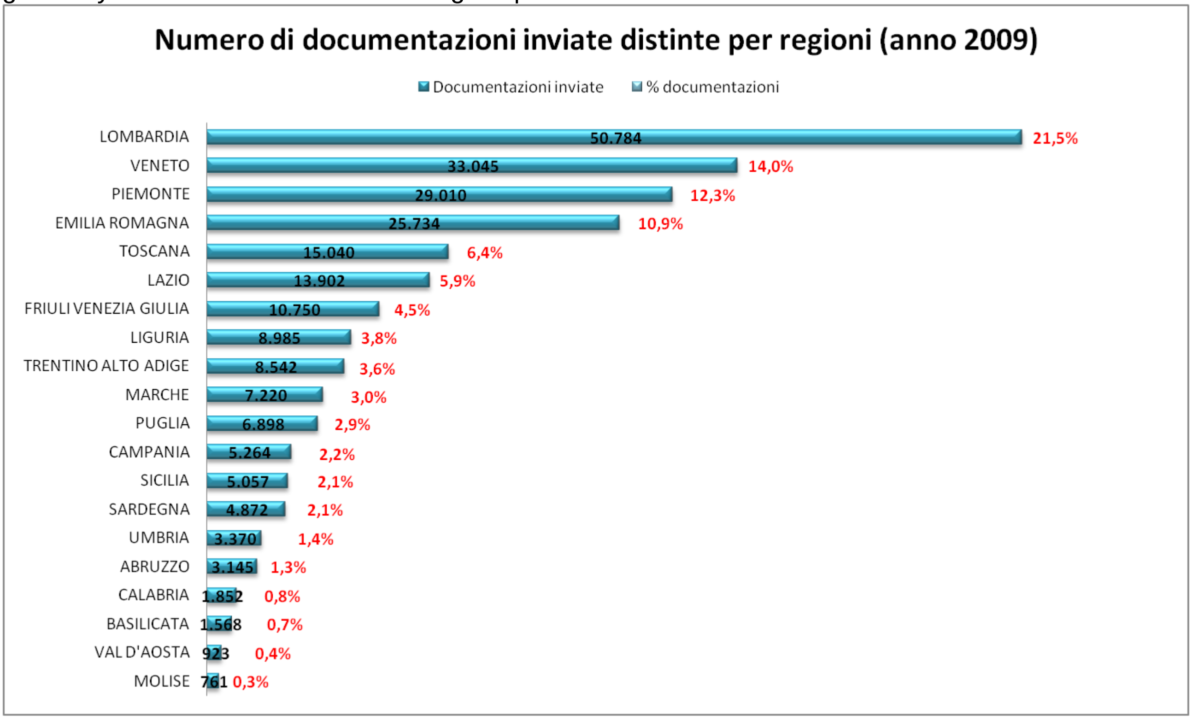


Figure 4 – Number of requests per Italian regions and %

Figure 5 shows the total number of interventions by type. What emerges is the clear dominance of the replacement of windows and insulation in walls and roofs (Section 345 of the 2007 Budget: about 55% of all jobs): of these, however, note the overwhelming majority of its replacement windows (it's the easiest thing to do and less invasive) with over 91% of these measures (which is approximately half of all), while only 3% is for the isolation of the vertical and horizontal opaque structures do not reach the 6%. Here is the ranking in replacement of heating systems (paragraph 347) with 27% of the total, the installation of solar panels (paragraph 346, over 14%) and the overall redevelopment of the building (paragraph 344) with just over 3%. And it's understandable: a comprehensive redevelopment of the building work is expensive and complicated, but gives excellent results in terms of energy savings and reduction of CO_2 emissions.

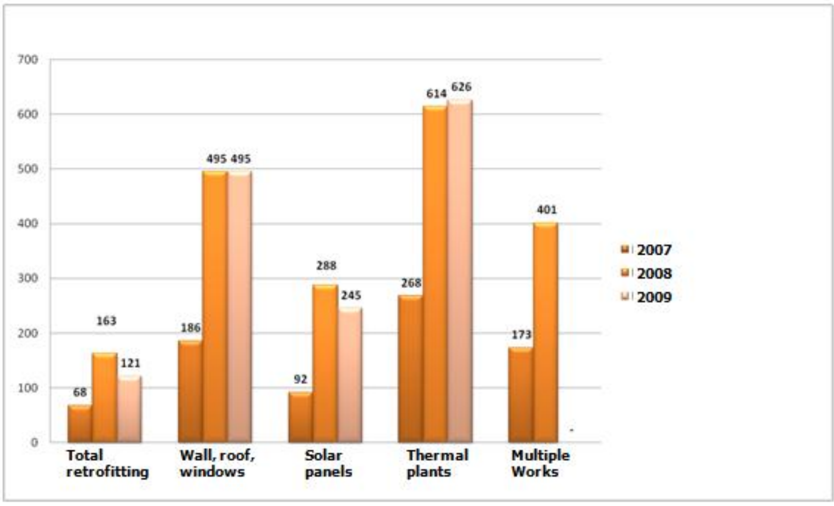


Figure 5 – Number of interventions per paragraph

To complete the picture, it's important to take a look at the performances obtained. Figure 6 shows the average cost of a saved kWh depending on the paragraph referred to and taking into account the estimated lifetime of the intervention. The installation of solar panels (p. 346) and the overall retrofitting of the building (p. 344) are far more convenient and the payback time is faster. It is important to be aware that paragraph 345 includes both the replacement of fixtures and the insulation of walls and garrets. Consequently the following elaboration presented by Figure 7 considers the individual types of intervention, identifying the average annual savings in MWh that each intervention can reach. The insulation of opaque horizontal structures (roofs, garrets and floors) give the best results in terms of energy efficiency recovery.

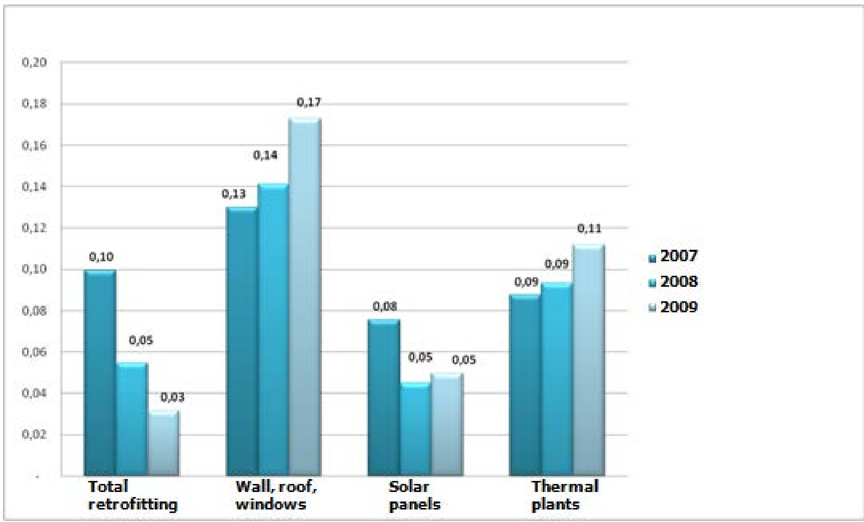


Figure 6 – Average cost for a saved kWh in 2007-2009 (considering the useful lifetime of plants)

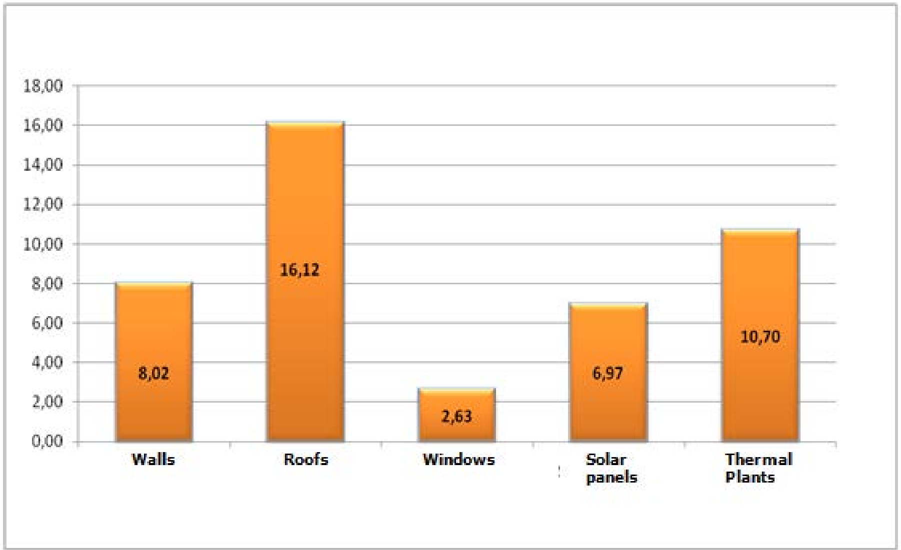


Figure 7 – Energy Savings achieved per type of intervention (MWh)

Among the five types of intervention incentivized, the best results were obtained with the insulation of floors, roofs and garrets (an average of 20.6 MWh saved per intervention/year, valued about € 1645, assuming a cost of kWh produced by conventional boiler powered with gas equal to 0.08 €). These are followed by the replacement of thermal insulation of walls, installation of solar panels and replacement of fixtures (2.56 MWh savings on average for the latter action equivalent to 164 € / year assuming the above). The above remarks highlight a ratio of 1 to 10 between the most and the less efficient interventions promoted. It 'clear, however, that the costs for achieving each of these works are very different and are usually directly proportional to the energy savings achieved.

Finally, we propose some considerations for the estimation of the effects of incentives. Referring to Figure 8 we can come-up with some results arising from a recent report prepared by the Working Group "Energy Efficiency" in collaboration with Cresme [2] covering the period 2007-2010. Granted that the 2010 data are only estimated, it can be seen that the total cost of the investment by users in four years would be € 11.1 billion. Out of these the 55%, amounting to 6.11 billion, is paid by the State. Given this expenditure, however, we have the following monetary returns: 3.1 billion of savings on energy bills of consumers due to lower consumption of energy during the lifetime of the plant; 3.25 billion in additional tax revenues on VAT, IRES, income tax paid by enterprises and professionals engaged in the rehabilitation projects, drawing their incomes; 4.31 billion for the increase in real estate income for the revaluation of reclassified buildings.

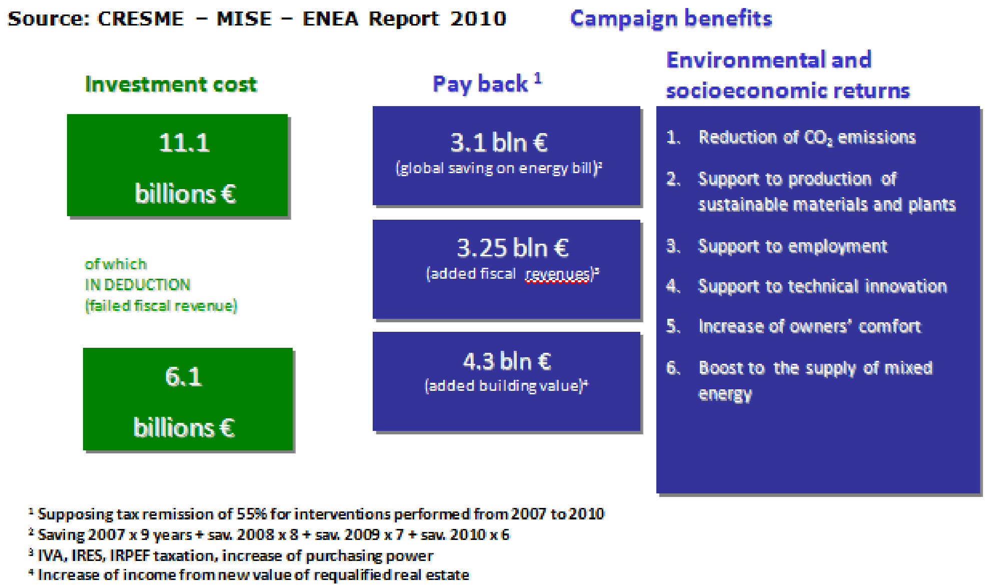


Figure 8 – Costs and benefits to 2015 of interventions performed from 2007 to 2010

These data amount to a total of € 10.66 billion which exceeded just by themselves the tax burden charged to the State. In addition there are other benefits, not quantified in detail, such as environmental and socio-economic returns, as of the reduction of CO_2 emissions resulting from reduced health and social costs, the support to industrial production of plants and sustainable technologies, backing to employment, overall youth, the drive for technological innovation and, last but not least, the increased comfort of the users of buildings and the improvement of the national energy supply mix.

Conclusions

After the presentation of the results of four years of tax deductions, we can point out that, compared to a certain remarkable loss of state income, benefits are certainly not less significant. In general, since 2007 a real boom in Italy in the energy efficiency market occurred, both in terms of industrial production, and in terms of employment for the workers involved, not only employees but also professionals. Just as an example, we can draw your attention to what has happened in the solar thermal market in 2009 (Fig. 9).

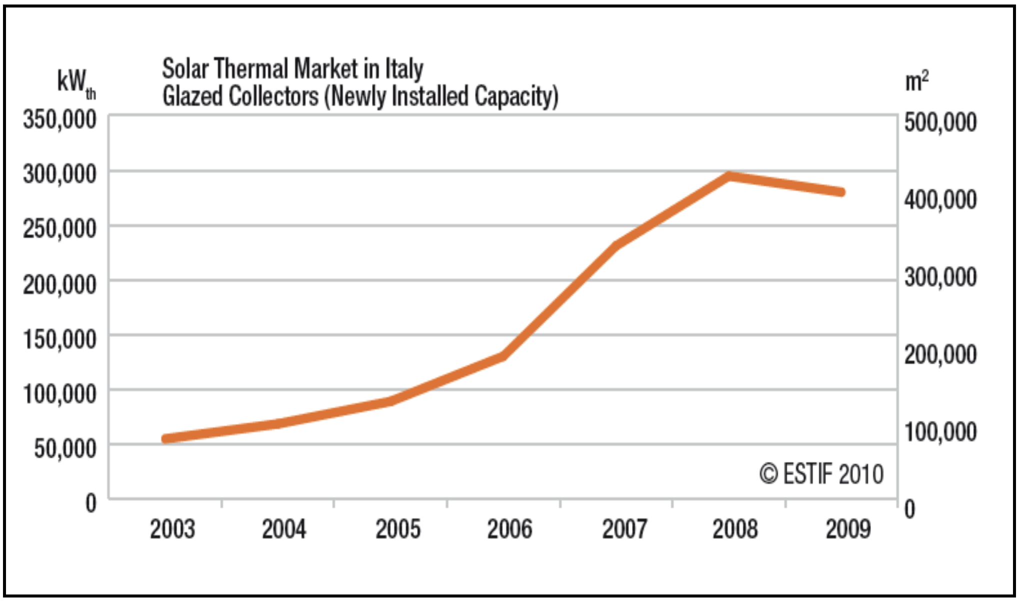


Figure 9 – Solar Thermal Market in Italy (2003 – 2009) – source: Assosolar

During this year the Italian market [3] is growing continuously and has consolidated its second position in Europe, after Germany, with 280 MWt installed during the year. The curve of the increase in power has soared just from 2007 as showed in Figure 8 [4], when the deductions started. From 2006 to 2008 the turnover of solar thermal quintupled, creating the opportunity for new jobs, estimated as one job every 80 kWt of new installed power. Considering that Italy is only at the 14th place among European countries in terms of installed capacity per capita, we realize the enormous exploitable capacity still available.

But beyond the solar thermal energy success, what could be the strategy to be pursued in the future to achieve maximum results and minimum charges from the system of incentives? Probably the best solution could be found in a mix of measures, by modulating different rates of deduction and in the identification of products/plants object to the incentive systems referring to their expected results and tasks of the Government in accordance with the international agreements and treaties. Some distortions arising from an examination of the interventions and in some cases of improper use of incentives can be easily corrected with targeted controls by using the database held by ENEA, or imposing more limited expenditure targeted for each job respect to the present ones that many times may seem abundant.

This system would be maintained and eventually stabilized and implemented, for example with an appropriate service of information and assistance to users. The contribution given by the working Group of ENEA has been deeply appreciated by the press, the operators and policy-makers as it has hit the target for energy efficiency and reduction of greenhouse gases. The Italian Government is hoped both to provide assurance in the medium - long term to end-users and to the Italian business system, in order to contribute to achieve the energy-environment targets signed by Italy at European level.

Controlling are demanded both to professional technicians who have to confirm declared savings in a preventive way and to Agenzia delle Entrate (National Revenue Agency)in a final way by asking proof of performed works to applicant. Popularity of the system is due to extreme generosity of the incentive, its simplicity (no authorizations or licenses required) and universality towards all social subjects. In 2010 we had an increase of requests of about 71% on 2009.

References

[1] http://efficienzaenergetica.acs.enea.it

[2] Enea-MSE-Cresme: “Analisi sull’impatto socio-economico delle detrazioni fiscali del 55% per la riqualificazione energetica del patrimonio edilizio esistente”. Roma, July 2010

[3] ESTIF (European Solar Thermal Industry Federation) 2010

[4] European Solar Thermal Industry Federation

Intelligent Energy Europe: new initiatives on consumers energy behaviour!

Christophe Coudun, Martin Eibl, Nathalie Cliquot, Francesco Ferioli & Vincent Berrutto

Executive Agency for Competitiveness and Innovation (EACI), European Commission, Brussels, Belgium

Abstract

The Intelligent Energy Europe (IEE) Programme is the European Union instrument to support actions aimed at overcoming the non-technological barriers for energy-efficient products in all sectors (http://ec.europa.eu/energy/intelligent). To this end, the programme funds information and behavioural change campaigns, awards, benchmarking, voluntary agreements, training activities, promotion and transfer of best practices, etc., in order to increase the market share of energy-efficient products and gradually phase-out less efficient products.

In 2010, the IEE programme called for actions helping consumers choose the most energy efficient products covered by the Eco-design Directive (e.g. household appliances, windows, lighting, etc.), as well as for actions directly raising awareness among various groups of individual consumers for issues covered by the Energy Services Directive (e.g. advanced metering and informative billing) or the Energy Performance of Buildings Directive.

This paper presents some of the most recent IEE projects relevant for the EEDAL audience, and is of interest for whoever is looking to learn from the IEE projects and/or is interested to apply to future Calls.

Introduction

The objective of the Intelligent Energy – Europe (IEE) programme is to contribute to secure, sustainable and competitively priced energy for Europe, by providing for action: (i) to foster energy efficiency and the rational use of energy resources; (ii) to promote new and renewable energy sources and to support energy diversification; (iii) to promote energy efficiency and the use of new and renewable energy sources in transport. The programme in particular contributes to the Energy Policy for Europe and its '20-20-20' goals: reducing greenhouse gas emissions by 20% compared to 1990 levels, increasing the share of renewables in final energy consumption to 20%, and reducing primary energy use by 20% compared to projections, all by 2020.

This programme has become the main Community instrument to tackle non-technological barriers to the spread of efficient use of energy and greater use of new and renewable energy sources. After a successful first phase from 2003 to 2006, Intelligent Energy – Europe has been continued with an increased budget of EUR 730 million for the period 2007-2013 [1]. The IEE programme is managed by the Executive Agency for Competitiveness and Innovation (EACI, formerly known as the Intelligent Energy Executive Agency) under powers delegated by the European Commission.

In operational terms the Intelligent Energy - Europe programme aims to:

- provide the elements necessary for the improvement of sustainability, the development of the potential of cities and regions, as well as for the preparation of the legislative measures needed to attain the related strategic objectives; develop the means and instruments to follow up, monitor and evaluate the impact of the measures adopted by the Community and its Member States in the fields addressed by the programme;

- boost investment across Member States in new and best performing technologies in the fields of energy efficiency, renewable energy sources and energy diversification, including in transport, by bridging the gap between the successful demonstration of innovative technologies and their effective, broad market uptake in order to attain leverage of public and private sector investment, promote key strategic technologies, bring down costs, increase market experience and contribute to reducing the financial risks and other perceived risks and barriers that hinder this type of investment;

- remove the non-technological barriers to efficient and intelligent patterns of energy production and consumption by promoting institutional capacity building at, *inter alia*, local and regional level, by raising awareness, notably through the educational system, by encouraging exchanges of experience and know-how among the main players concerned, business and citizens in general and by stimulating the spread of best practices and best available technologies, notably by means of their promotion at Community level.

Intelligent Energy - Europe covers action in the following fields:

- Energy efficiency and rational use of resources (SAVE component), including improving energy efficiency and the rational use of energy, in particular in the building and industry sectors; or supporting the preparation and application of legislative measures.

- New and renewable energy resources (ALTENER), including promoting new and renewable energy sources for centralised and decentralised production of electricity, heat and cooling, and biofuels, thus supporting the diversification of energy sources; integrating new and renewable energy sources into the local environment and the energy systems; or supporting the preparation and application of legislative measures.

- Energy in transport (STEER) to promote energy efficiency and the use of new and renewable energy sources in transport, including supporting initiatives relating to all energy aspects of transport and the diversification of fuels; promoting renewable fuels and energy efficiency in transport; or supporting the preparation and application of legislative measures.

- Integrated initiatives combining several of the aforementioned fields or relating to certain Community priorities. They may include actions integrating energy efficiency and renewable energy sources in several sectors of the economy and/or combining various instruments, tools and actors within the same action or project.

The above fields and objectives are valid for the whole IEE programme duration, i.e. from 2007 to 2013. However, every year a work programme is elaborated with the EU Member States to set a number of more specific, action-related objectives.

What is an IEE project?

A successful IEE-funded project should have a strong focus on promotion and dissemination activities and help deliver the key EU climate change and energy objectives. Project proposals should match the priorities of the annual Work Programmes, involve at least three partners from three different countries (a typical IEE project is carried out by eight-nine organizations), and take two to three (maximum) years to deliver results. It is important to notice that an IEE project is not a “hardware” type investment or research & development project, for which other funding opportunities are available at EU level (e.g. FP7).

Any public or private organisation established in the EU, Norway, Iceland, Liechtenstein, Croatia, or (since 2011) the Former Yugoslav Republic of Macedonia can apply for funding, as well as international organizations, whereas natural persons cannot. The total costs of IEE projects are generally between one and two million EUR, supported up to 75% by the programme (grants). It is highly recommended that any potential proposer be familiar with the key documents published each year: the Work Programme providing backgrounds, priorities and budgets, the Call for Proposals presenting the evaluation criteria, priorities and deadlines, and the Application forms & Guide for Proposers that constitute essential forms and guides to draw up and submit proposals. All these documents are available on the programme web site.

New IEE projects on energy behaviour

The Intelligent Energy Europe programme is an appropriate instrument to pull the market towards more sustainable and energy-efficient products, as it implements and complements the current EU policy (e.g. Ecodesign [2] and Energy Labelling [3] directives or Energy Star [4] and Tyre Labelling [5] regulations). A wide range of products have already been addressed in more than 30 projects (see a selection in [6]), e.g. lighting products, domestic appliances, servers, boilers, air conditioners, motors, pumps, lifts, distribution transformers or construction products.

In 2010, the IEE work programme included a specific priority on consumer behaviour to help them choose the most energy efficient products covered by the Eco-design Directive (e.g. household appliances, windows, lighting, etc.), and called for actions directly raising awareness among various groups of individual consumers for issues covered by the Energy Services Directive [7] (e.g. advanced metering and informative billing) or the Energy Performance of Buildings Directive [8].

Out of the 54 proposals received under this consumer behaviour priority, seven were selected for support by IEE and are presented below. Their EU funding was committed in April-May 2011, and most of the actions were kicked-off in the same period.

Information campaigns

Maximising Topten Communication on Top Runner Products

EURO-TOPTEN-MAX

Topten websites are designed to showcase the top runners in a number of energy-using product groups. They build on independent, reliable and continuously updated market surveys. The Euro-Topten-Max goal is for the 19 national Topten websites (covering 90% of Europe's population), through highlighting top runners and championing best available technology, to increase the demand for top runner products (raising awareness of their benefits) and to encourage manufacturers and retailers to make best performing products available across Europe. The work programme focuses on developing a technical basis for the websites in collaboration with manufacturers, reaching out consumers through extensive use of the media and developing partnerships with retailers (using Topten at point of sale) and professional buyers. A European Topten Product Competition will be organised.

Energy BITS: Young people and media for a low energy footprint

E-BITS

E-BITS is a cross-media project and campaign. It will go over standard communication methods (such as articles, distribution of kits, brochures and meetings) and jointly use and synergistically combine distribution platforms like TV broadcast, on generic national TV channels and dedicated satellites theme channels (Science, Educational and Cultural Channels), web streaming and download. In order to optimise especially the young viewer engagement and change of behaviour, the project will include also interactive features such as an interactive web documentary, a “serious game” (using young peoples’ enthusiasm for gaming to achieve a pedagogical aims), and a user-generated-content module where young people create, share and comment their own videos on the subject.

The major expected outputs could be summarised therefore in four results:
1.“The Series” a collection of professional productions of (24 documentaries) on energy issues related to 20-20- by 2020 objectives and EU directives contents.
2.The production of a web interactive documentary to be broadcasted on the project's portal and to be promoted through all media partners links and streams.
3.The production of a “serious game” on the portal to enhance young students participation on energy issues.
4.“Have Your say”, a user generated module with productions of own videos realized by young students within school classes.

The main project objectives are:
- to raise awareness on sustainable issues among youngsters, acting as vehicle of information toward families and communities;
- to provide a large scale information sharing on energy issues;
- to let youngster have a close to real life experience on sustainable issues;
- to let target changing their daily behaviors;
- to provide a cross media experience on sustainable issues.

Promoting best practices to support energy efficient consumer behaviour on European islands

PROMISE

Maximising energy savings and reaching high energy efficiency levels are crucial challenges currently faced by the EU. Residential energy demand is rapidly increasing due to larger homes, new services and additional appliances, putting a strain on the economies and energy infrastructures of EU regions. Moreover, domestic energy use is still largely invisible to the user and this is a prime cause of wastage. Most people have only a vague idea of how much energy they use for different purposes and what difference they could make by changing day-to-day behaviour or investing in energy efficiency measures. The overall goal of the project PROMISE is to support better information provision by tackling the main barriers that still exist today for taking up energy efficient behaviour among consumers. Through PROMISE, households will be approached and supported in choosing the most energy efficient products and encouraged to reduce household consumption in gas and electricity. Furthermore, they will learn about successfully implemented measures which generate, through financial incentives and ownership models, a more participatory involvement in energy concerns.

Energy advice

MOVing from Inspection to Domestic Advice by service companies

MOVIDA

The European Performance of Building Directive (EPBD), Directive 2001/92/EC, requires that Member States (MS) organise inspections of Boilers and of Air Conditioning systems, to reduce energy consumption and limiting carbon dioxide emissions, and that these inspections be carried out in an independent manner by qualified and/or accredited experts, whether operating as sole traders or employed by public or private enterprise bodies. The “recast” of EPBD, Directive 2010/31/EU, modifies these articles, requiring in art. 15 that the inspection report contains also a comparison of the energy performance of the system inspected with that of (i) the best available system feasible and (ii) a system of similar type for which all relevant components achieve the level of energy performance required by the applicable legislation, and recommendations for the cost-effective improvement of the energy performance of the system of the building or parts thereof. The final users will therefore obtain a targeted information and advice to be effectively moved towards a better energy efficiency and use of renewable energy sources.

Energy Neighbourhoods2 - The Energy Challenge

EN2

Energy Neighbourhoods2 is the successor of the award-winning IEE project Energy Neighbourhood and builds on the idea of an energy saving bet between cities and citizens. Cities challenge their citizens in two consecutive years to save at least 9% energy in 4 months compared to the previous year. 5-12 households form an 'Energy Neighbourhood' and compete to save 9% energy or more in line with the 9% target of the Energy Services Directive. The approach combines a competition on local, national and EU level with other measures, such as training for households and municipalities, consumption monitoring and local climate campaigns. Throughout the process, knowledge will be provided to all participating households and information events will be organised. Participating households will be supported by specially trained "Energy Masters", volunteers from the neighbourhood to motivate, supervise monitoring and provide material, such as 'DIY energy audits'. Local authorities will be supported by the partners to implement the project. The project's main results will be to reduce energy consumption in private households and raise awareness of energy efficient products and climate protection policies.

Building on the success of the previous project and based on households' needs, Energy Neighbourhoods2 will newly:
- introduce individual carbon footprints;
- adapt duration and goals of the bet;
- expand to new target groups;
- include an evaluation phase, resulting in improved strategies and tools for new regions;
- provide information on CO_2 friendly consumer choices and involve new participants.

Energy Neighbouhoods2 will also hold a large scale campaign to raise the awareness of a broad public, using traditional and new social media. Participants will share their experiences using peer-to-peer communication. The project idea will be transferred throughout Europe via key stakeholders on national and EU level to extend the project and its tools to new regions in the future.

Fighting fuel poverty

Energy Check for Low Income Households

EC-LINC

Private households make up 25% of the EU final energy needs and are therefore an important target group for reaching the European objectives for energy efficiency and CO_2 reduction. While measures of consumer information (Energy Label) and minimum efficiency requirements (Eco-Design Directive) are very necessary, low-income households need additional stimulus to become more energy efficient. Low-income households often cannot afford the initial investment for high-efficiency domestic appliances, so that less efficient second-hand appliances are used. Furthermore, language or social barriers make it difficult to inform this target group about energy efficiency issues. This project aims at establishing tailored information and consultation approaches to assist low-income households in saving energy and water. The consultation implies free-of-cost installation of low-cost devices to save water and energy (e.g. compact fluorescent lamps, switchable plug connectors, tab aerators) plus advice for energy saving behaviour.

By combining the know-how of energy experts with the skills of social economy or welfare organisations, the following goals are being pursued:
- environmental goals: saving of electric power, heating energy, water, CO_2 emissions, by means of low-or-no cost- measures;
- social goals: reducing energy and water expenses in the households addressed, as well as for public authorities responsible for covering these costs for low-income households;

- labour market goals: qualification of long-term unemployed or low-skilled people to assist households in energy conservation;
- educational goals: information of households on the economical usage of energy and water.

Taking advantage of experiences of existing initiatives, specific approaches to assist low-income households in saving energy and water will be demonstrated in the participating countries. The results will be evaluated and transported to decision makers to initiate replication in further projects.

ACtions in low income Households to Improve energy efficiency through Visits and Energy diagnosis

ACHIEVE

There is currently a number of reasons why households in particular those in energy poverty do not take up the energy saving message. These include lack of access to information from trusted sources and competing priorities for home-owners also lack of structured local initiatives from municipalities, landlords and other key actors. ACHIEVE will recognise and learn from best practises throughout Europe, it will identify those in most need in specific areas, evaluate options and develop a mixture of actions plans and practical solutions to reducing energy poverty and carbon emissions by working with home owners, tenants, landlords and other relevant organisation. ACHIEVE will do this by identifying and mobilising new groups of people (such as students and long term unemployed persons), and support them in carrying out a large scale campaign of home visits to households who have hitherto not had access to help and support. As such it will result in changing behaviour and introducing energy efficiency measures to the homes and reducing overall energy consumption and energy poverty. The project will initially analysis the optimal way to reach various categories of citizens, by researching their current circumstances, ways to target them and the most effective structures and stakeholders to mobilise when talking to them. The final steps will be to find solutions to launch genuine consideration of the building scale when thermal improvement works are needed: by connecting better tenants and landlords, informing, motivating and orientating them with easy to understand and tailored documents and methods.

Conclusion

Further information on projects supported by the IEE programme is available for public download, at http://ieea.erba.hu/ieea or http://www.iee-library.eu. To be selected for funding, projects should build on existing actions, involve the right market actors, demonstrate community added-value, be cost effective, and have a high impact. Altogether projects funded under the IEE programme are expected to contribute to secure, sustainable and competitively priced energy for Europe.

References

[1] Berrutto, V. & Schmid, W. (2007) A turning point for the “Intelligent Energy Europe” programme. eceee summer study, 2007, 345-353.

[2] Directive 2009/125/EC of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products (recast).

[3] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

[4] Regulation No 2422/2001 of the European Parliament and of the Council of 6 November 2001 on a Community energy efficiency labelling programme for office equipment.

[5] Regulation (EC) 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters.

[6] Intelligent Energy Europe (2008) Energy-efficient products. Consume green. 22 projects funded by the IEE programme.

[7] Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC.

[8] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

Drivers of electricity consumption until 2050

Stephan Renner, Paul Pfaffenbichler

Austrian Energy Agency (AEA)

Abstract

This paper summarizes the main results of a study on the development of electricity demand in Austria by 2050 with a focus on private households and the transport sector. Three scenarios were elaborated. The results were calculated using a model of the Austrian energy system that was developed by the Austrian Energy Agency (AEA). In the transport sector the dynamic simulation model SERAPIS (Simulating the Emergence of Relevant Alternative Propulsion technologies in the car and motorcycle fleet Including energy Supply) was used. The overall results show that electricity will become ever more important in the four decades to come. While (mainly due to efficiency improvements) total electricity consumption will decrease in private households, electricity will significantly increase in the transport sector. In all sectors, however, the share of electricity in final energy consumption will increase. Electricity as energy carrier will play an important part in the transformation of the economy to a post-fossil age.

Introduction

What are the main drivers and possible paths of electricity demand until 2050? The Austrian Energy Agency developed three scenarios of electricity demand development in Austria in the four decades to come for the sectors private households, services, industry and mobility.

In this paper we present some of the main results of this comprehensive study for the sectors private households and transport. In the first part, we identify the main drivers of electricity demand scenarios from past development. This is followed by a presentation of the scenarios "Waiting," "Chasing" and "Steering," its narratives and main assumptions. We then illustrate three developments paths in private households and transport based on the assumptions using a model of the Austrian energy system that was developed by the Austrian Energy Agency (AEA). Additionally, in the transport sector the dynamic simulation model SERAPIS is presented which was used to estimate the development of electric vehicles based on various assumptions.

Past developments: increasing consumption, decreasing intensity

In the last four decades we observed two parallel developments: a constant increase in power consumption and a steady decline in energy and electricity intensity. Since 1970 electricity consumption in Austria has increased by an average of 2.7% annually with a close correlation between final energy consumption, electricity consumption and economic growth. At the same time, electricity intensity measured as electricity consumption per unit of GDP, has decreased by 0.6% annually. This trend in Austria is consistent with European and global developments where the increase in electricity consumption historically outpaced efficiency improvements, fuelling the debate on the link between energy efficiency and consumption [16] [5] [17-18].

The importance of electricity as energy carrier has increased in the past and is expected to further do so in the future. The share of electricity in the energy mix of households and services has grown significantly since 1970. Additionally, the share of electricity in final energy consumption rose in almost all branches of the manufacturing sector. In 2007 almost half of total electricity consumption was used in the industrial sector. The other half is roughly divided between households and the service sector.

A second trend is apparent: the demand for heat declines, electricity demand rises. In private households, electricity consumption has increased by 9% since 1995 while final energy consumption has remained at just about the same level. This trend is in line with European developments [5]. A higher degree of equipment in electronics and ICT applications, the increasing use of heat pumps as well as changes in demographic patterns and wealth are the main responsible factors for this development. The increasing number of households and size of dwellings (residential usable space increased by 34% between 1994 and 2008) and the living area per person (m^2/person) is driving electricity consumption. Moreover, many electric appliances have become standard equipment in households (such as dishwashers, clothes dryers). In the transport sector electricity has so far been primarily used in rail traffic. In Austria, the share of electricity in total final energy consumption of the transport sector in 2007 was not higher than 3%.

Narrative, general assumptions and model approach

In order to model future trends in electricity demand, three scenarios were developed. These scenarios differ in their assumptions about economic development, availability and prices for raw materials, technical development, and regulatory measures to influence electricity demand.

The scenario "**Waiting**" is the reference scenario that presumes a continuation of the past trends with improvements in the efficiency of electric applications. Political measures will have a modest incentive effect towards more efficient use of energy, reflecting little ambitious international agreements. Energy prices will increase moderately in the long term. The expected increase in oil prices is based on the forecasts of the World Energy Outlook [32]. In both electric appliances and electricity production we assume no radical technological leaps.

The scenario "**Chasing**" is characterized by exogenous shocks and knee-jerk political reactions to steeply rising oil prices. In a highly networked global economy, policies run after an international development, rather than proactively confronting it. Fossil fuels are no longer available as cheap energy sources. Due to a significant decline in oil depletion rates of currently used fields (see, e.g. [21][2]), crude oil prices will increase significantly.[1] The heavy dependence on fossil fuels and the political conflicts over access to these resources lead to high volatility in energy markets and impede sustained economic growth and innovation in renewable energy sources [12][22][30]. The technological development is driven primarily by high energy prices, which is however hampered by a highly volatile economic development. The focus of innovations lies primarily in more efficient equipments for end-users, less investment is expected for infrastructure. International agreement focus on curbing the effects of global warming but fail to tackle the causes and to internalize the external costs.

Finally, in the scenario "**Steering**" we assume that there will be both nationally and internationally coordinated efforts to curb greenhouse gas (GHG) emissions, to internalize external costs and develop innovative and sustainable low-risk technologies that succeed the fossil-based electricity production. Similar to the scenario "Chasing" we assume that the increasing scarcity of fossil fuels will soar oil prices from 2030 onwards. However, internationally coordinated adaptation to a post-fossil energy system causes a decrease in demand and reduces the dependence on volatile oil prices [12]. High public investment in infrastructure offset the negative economic effects from high oil prices. The timely adaptation to a post-fossil fuel economy contributes to stable and sustainable economic growth, yet, nevertheless, at a much lower level than in the past decades.

The three scenarios were developed using a complete model of the Austrian energy system developed by the Austrian Energy Agency (AEA). This model displays the flow of energy from primary energy production through various stages of transformation to useful energy. The determining factors are the flow of energy conversion technologies used and the development of demand for individual types of useful energy demand which are, in turn, influenced by the development of macro-economic factors such as GDP and population growth. For the development of this model the TIMES model generator was used that was developed by the International Energy Agency (IEA).

However, it is important to note that these scenarios are not forecasts, that is, not a prediction of future developments. Rather, they represent three alternative internally plausible and consistent development paths which might occur until the middle of the 21st century, given certain assumptions and conditions. The set of assumptions that have to be made and possible combination of them,

[1] The fact that the depletion rates of currently used fields is declining, was acknowledged by the chief economist of the IEA, Fatih Birol: "The existing [oil] fields are declining so sharply that in order to stay where we are in terms of production levels in the next 25 years, we have to find and develop four new Saudi Arabias" [39].

indicate that the range of development paths can be enormous, therefore underlining the uncertainty concerning how the real energy system will, in the end, develop [25].

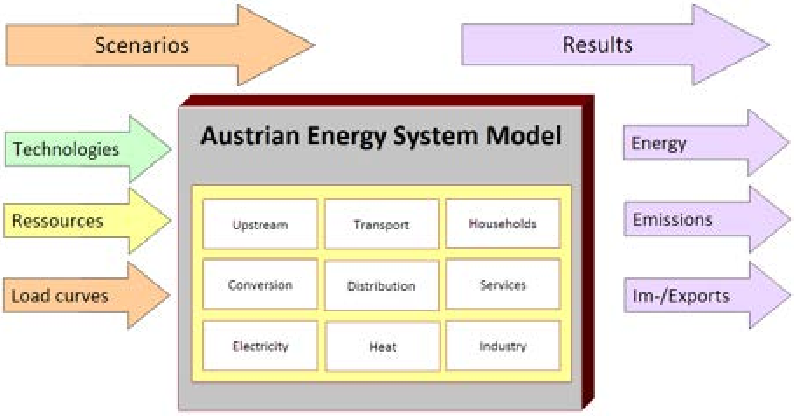


Figure 1: Structure of the model of the Austrian energy system

As was mentioned above, we assumed moderately rising crude oil prices for the scenario "Waiting" and, starting in 2030, sharply rising prices for the scenarios "Chasing" and "Steering." The assumptions for the price development until 2030 are for all scenarios below those of the International Energy Agency or the U.S. Energy Information Administration. In the years 2030-2050 stronger price increases are expected. The background to this is the assumption that by 2020 costs will rise for crude oil due to the exhaustion of the current mines. The depletion of oil will result in increasing investment needs and diminishing returns which will have effects on oil prices (see, e.g. [2][29][19-20]).

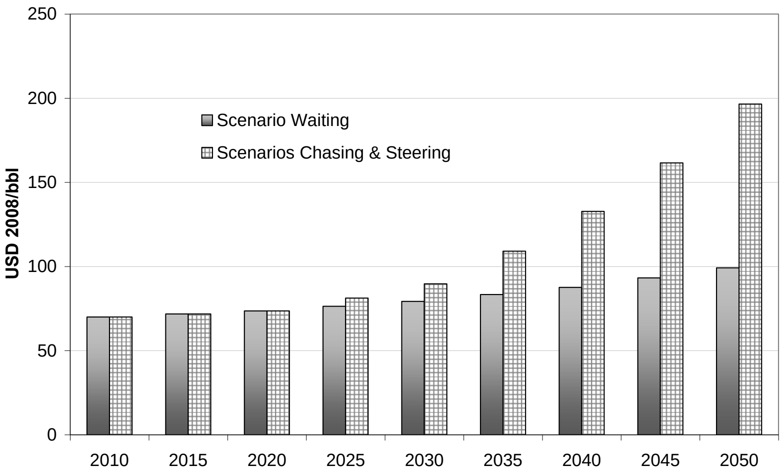


Figure 2: Development of crude oil prices in USD2008/bl 2010-2050

All three scenarios use identical assumptions for the development of population in Austria [36]. Between 2010 and 2050, the total population will increase by about 13% from 8.4 million in 2010 to 9.5 million in 2050. The age structure is shifting significantly towards elderly population. In 2050 one in three people will be 60 and more years old. The group of people over 75 years old will increase from 2008 to 2050 from 662,000 to over 1.5 million. Due to the expected migration, the aging process of the population in urban areas will be lower than in rural parts of the country.

Table 1: Population forecast for Austria 2010-2050 [36]

Year	**Demographic structure in Austria, 2010-2050**						
	Total	< 15 Years	15 - 60 Years	60 and over	< 15 Years	15 - 60 Years	60 and over
	absolute figures (in million)				in %		
2010	8.39	1.24	5.21	1.93	14,8	62,1	23,1

Year	Demographic structure in Austria, 2010-2050						
	Total	< 15 Years	15 - 60 Years	60 and over	< 15 Years	15 - 60 Years	60 and over
	absolute figures (in million)				in %		
2015	8.57	1.22	5.27	2.07	14,3	61,5	24,2
2020	8.74	1.24	5.22	2.27	14,2	59,7	26,1
2025	8.90	1.26	5.07	2.55	14,2	57,0	28,7
2030	9.04	1.28	4.95	2.80	14,2	54,8	31,0
2035	9.17	1.27	4.93	2.95	13,9	53,8	32,2
2040	9.28	1.26	4.96	3.04	13,7	53,5	32,8
2045	9.38	1.26	4.96	3.15	13,5	52,9	33,6
2050	9.46	1.26	4.96	3.23	13,4	52,4	34,2

In addition to the demographic structure, in all scenarios similar assumptions were used regarding the number of households and persons per dwelling. We expect an ongoing trend towards smaller household sizes with a growing number of households and decreasing number of persons per households. In the period 2001-2050, the number of people per dwelling decreases in all three scenarios from 2.4 to 2.2 persons. We do differentiate between the scenarios, however, the residential floor space available.

Table 2: General assumptions about population and housing development

Indicator	Period	Growth
Population	2010–2020	0,4 %
	2020–2030	0,3 %
	2030–2040	0,3 %
	2040–2050	0,2 %
Number of households	2010–2020	7,0 %
	2020–2030	4,8 %
	2030–2040	4,3 %
	2040–2050	3,0 %
Persons per apartment	2010–2020	-2,6 %
	2020–2030	-1,3 %
	2030–2040	-1,6 %
	2040–2050	-1,0 %

Developments in private households

Conceptually, electricity consumption in the residential sector is determined by the number of electric devices, the specific consumption and the time of use of these devices. While we could observe decreasing specific consumption in the past and expect further efficiency improvements in the future, the number of devices and the time of use will increase due to changing wealth, demographic structures and lifestyles. Table 3 provides an overview of some of the main input data for the development of future electricity consumption in private households.

Number and size of households

The increasing number of households and size of living area combined with a significant decrease in the average number of persons living in a household leads to an increase in electricity consumption of households. Regardless of the size of homes or the people living in a household an appropriate basic level of equipment with appliances per household can be expected. The average floor space of a household will increase from around 100 m² in 2010 to 116 m² in scenario “Waiting” and will decrease in the other scenarios, mainly due to increased urbanization, high energy prices and, in the case of scenario “Chasing,” slower economic growth.

Electrical equipment in households

The number of electrical appliances available in private households will increase with GDP and lifestyle changes. As of 2008, 100% of Austrian residential homes were equipped with refrigerators and 60% with a freezer. Washing machine stock has reached saturation, reaching penetration rate levels of around 100% in all the EU-27 countries [5]. The largest increase could be observed in the equipment of households with consumer electronics. Information and Communication Technologies are among the fastest growing electricity end-use in the residential and tertiary sector (ibid.). In Austria, 76% of private households now own a computer, 96% a television, 75% a HiFi-System. Around 90% of the households have an electric stove while at the same time the percentage of households with a natural gas stove decreased from 35% in 1974 to around 12% in 2008. Around one third of the private households already own a clothes dryer. This trend towards ever more electric appliances will continue and is a main driver for growing electricity demand in the residential sector.

Reduction in specific consumption of devices

While the number of electrical devices will continue to grow in the decades to come, a trend that will also persist is the reduction in the specific consumption. With technological development we can expect a drastic improvement in the efficiency of devices in private households. Energy Efficiency Indicators for most household appliances have decreased. For example, the energy efficiency index (EEI) of cold appliance improved continuously between 1993 and 2007, reaching 44% efficiency improvement over 14 years [5]. Even if the rebound effect is taken into account [10], the reduction of specific electricity demand acts as a negative driver for future electricity demand.

Growing time of use of available electrical appliances

Growing comfort needs lead to the increasing use of existing appliances. The development of the total use time is dependent on household income and the price of electricity. Together with the growing number and size of residential apartments and the increasing penetration rate of electrical appliances, this development is a positive driver for electricity demand.

Table 3: Assumptions for developments in private households 2000-2050 (Source: AEA)

Category	Unit		2000	2010	2020	2030	2040	2050
Residential floor space	mil. m²	Waiting	297.8	362.7	415.9	454.1	485.4	507.3
		Chasing	297.8	362.9	372.0	381.4	390.7	400.0
		Steering	297.8	362.9	377.0	391.4	405.7	420.0
Residential floor space per person	m²	Waiting	37.0	43.2	47.5	50.2	52.3	53.6
		Chasing	37.0	43.2	42.5	42.1	42.1	42.3
		Steering	37.0	43.2	43.1	43.3	43.7	44.4
Residential floor space per household	m²	Waiting	89.0	100.2	107.3	111.9	114.7	116.4
		Chasing	89.0	100.2	96.0	94.0	92.3	91.8
		Steering	89.0	100.2	97.3	96.4	95.9	96.4
Heat demand	kWh/m²	Waiting	201	143	119	94	70	45
		Chasing	201	143	119	93	66	40
		Steering	201	143	119	88	56	25
Energy intensity for cooking per person	kWh	Waiting	102.8	102.9	98.6	94.5	90.6	86.9
		Chasing	102.8	103.4	100.8	98.3	95.9	93.5
		Steering	102.8	102.6	97.5	92.7	88.1	83.7
Energy intensity for water heating per person	kWh	Waiting	1,282	1,260	1,185	1,110	1,035	960
		Chasing	1,388	1,252	1,152	1,052	952	853
		Steering	1,388	1,252	1,152	1,052	952	853
Energy intensity of electric appliances per apartment	kWh	Waiting	2,182	2,103	2,128	2,154	2,180	2,205
		Chasing	2,182	2,103	2,139	2,111	2,083	2,056

Category	Unit		2000	2010	2020	2030	2040	2050
		Steering	2,182	2,103	2,125	2,069	2,042	2,028
Share of air-conditioned space of total residential floor space	%	Waiting	0.5%	1.0%	3.7%	4.6%	3.8%	3.0%
		Chasing	0.5%	1.0%	2.3%	2.6%	1.8%	1.0%
		Steering	0.5%	1.0%	0.7%	0.5%	0.4%	0.3%

Consequences for final energy and electricity consumption

What is the impact of these main developments on electricity consumption in the residential sector? What all three scenarios have in common is that the total final energy consumption of households in the period 2010 to 2050 will drop significantly, continuing a trend that has been observed for the last decade (Figure 3).

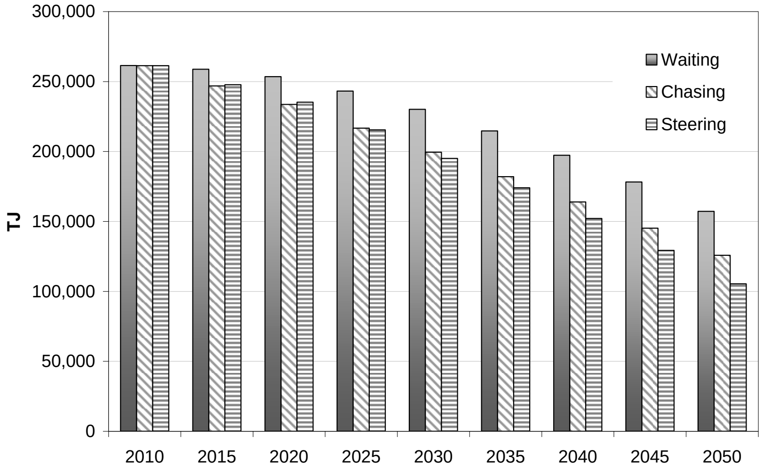


Figure 3: Development of total final energy consumption in private households in Austria, 2010-2050

The main reason for the trend to lower energy demand in the residential sector is that stricter building codes result in lower heat demand of buildings. The heating intensity of households in Austria (i.e. the space heating demand per 1000 m²) has been declining already since 2003. With existing political measures and taking into account a rebound effect for space heating of around 20-30% [14], the final energy consumption for space heating, hot water and cooling is expected to decline in the period 2010 to 2050 by 49% (in scenario “Waiting”). In scenario “Steering,” final energy consumption for space heating, domestic hot water and cooling will decline by more than 70% in the period 2010 to 2050. This is, of course mainly due to improvements in the building envelopes: heat demand is expected to decrease in the Steering-scenario on average from 143 kWh/m² in 2010 to 56 kWh/m² in 2040 and 25 kWh/m² in 2050. However, regardless of the expected efficiency improvements through the refurbishment of existing buildings and an ambitious building code for new buildings, there will still be some heat requirement in 2050, particularly for existing buildings. Even in 40 years can this head demand not be covered by solar systems alone. In private households, we expect energy demand for space heating, hot water and cooling, depending on the scenario, between 67 and 115 PJ in 2050.

The share of electricity in final energy consumption of the residential sector will increase. In passive-houses and zero-/plus-energy buildings, energy for space heating, hot water and cooling will mainly be provided by combined solar systems with heat pumps. However, in absolute terms, due to decreasing energy demand for space heating and hot water, we expect that electricity consumption for space heating will be cut in half from 2010 to 2050. Generally, there will be a drop in the use of fossil fuels for space heating and hot water treatment (more in the scenarios “Steering” and “Chasing,” which consider rising energy prices, than in “Waiting” where only moderate prices increases are assumed) in favour of renewable energy sources and ambient heat in particular.

Total electricity consumption in the residential sector is expected to decrease in all scenarios, reflecting the significant improvements in the efficiency of electric appliances and, most importantly, the building envelope. While electricity demand for space heating drops strongly, energy consumption for electric household appliances (refrigerators, washing machine, computers, etc.) will increase in all scenarios. This reflects the strong growth in appliances that is stronger than the expected efficiency gains. Figure 4 illustrates the development of total electricity demand in the residential sector for the period 2010-2050.

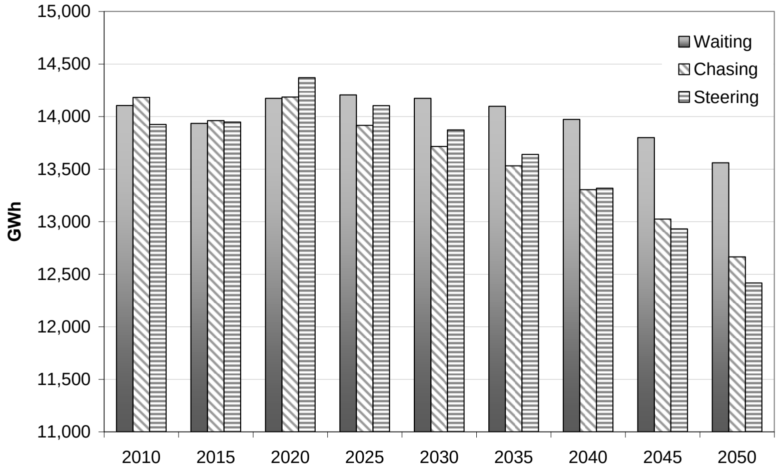


Figure 4: Total electricity consumption in private households (including heating), 2010-2050

Developments in the transport sector

In Austria, the transport sector stands out as the sector with the highest growth rate of greenhouse gas emissions and energy consumption. Regarding emissions in the framework of Austria's Kyoto obligations, the transport sector in 2009 emitted 21.7m tons of CO_2-equivalents, which is 54.4% more than in the base year 1990. Total emissions – contrary to Austria's obligations – also rose since 1990, however only by relatively moderate 2.5%. This positioned the transport sector the furthest away from its emission reduction goals of all sectors in Austria [38]. Since 1990 the final energy consumption in the transport sector rose by 71% to a total of 357 PJ in 2009. This makes the transport sector in absolute terms the largest Austrian sectoral final energy consumer. As a consequence, the transport sector is of utmost importance for any policies that aim at curbing GHG emissions and energy consumption. In the recently adopted Austrian Energy Strategy of the Austrian government battery electric and hybrid vehicles are seen as a promising way to increase energy efficiency, reduce greenhouse gas emissions and dependence on fossil fuels while still maintaining motorized individual mobility. Moreover, this strategy also supports tax relieves for electric vehicles and public funds for infrastructural and organisational measures [6].

In order to be able to assess the effectiveness of the proposed policy instruments and to formulate a successful rollout strategy, the Austrian Energy Agency developed the dynamic simulation model SERAPIS (Simulating the Emergence of Relevant Alternative Propulsion technologies in the car and motorcycle fleet Including energy Supply). The aim of SERAPIS is to facilitate an integrated estimation of the development of the vehicle fleet including the share of different propulsion technologies, the resulting requirements for utilities and greenhouse gas emissions. SERAPIS consists of the following five modules:

- a model of the total vehicle fleet,
- a model of the propulsion technology choice,
- calculation of the demand for electricity,
- calculation of the requirements for electricity supply from renewable resources and
- calculation of CO_2-emissions.

SERAPIS is based on the principles of Systems Dynamics The discipline Systems Dynamics was founded by John Forrester and his colleagues in the late 1950ies at the Massachusetts Institute of Technology (MIT). Systems Dynamics is a set of qualitative and quantitative tools to describe and analyse systems and their dynamic behaviour. Causal Loop Diagrams are the major qualitative method. They are useful to facilitate the description, communication and discussion of any kind of system. Furthermore they allow statements about the principal system behaviour, i.e. whether a state of dynamic equilibrium can be reached or not. Causal Loop Diagrams often form the basis for quantitative dynamic modelling. This technique was also used as a starting point in the development of the propulsion technology choice model. The major quantitative Systems Dynamics concept of stocks and flows is utilized to model the fleet development and choice of propulsion technology. A detailed description of the methods can be found in [3][35][37].

Fleet model

The calculation of the fleet development is based on a linear elasticity model which modifies the number of vehicles relative to a baseline scenario (see Equation 1). The fleet development model is embedded in the data user interface in MS Excel®.

$$N_k(t) = e * N_0(t) * \frac{C_k(t)}{C_0(t)}$$

Equation 1: Linear elasticity model

In Equation 1 $N_k(t)$ represents the number of vehicles in a scenario *k* at year *t* while $N_0(t)$ represents the number of vehicles in the baseline scenario *0* at year *t*. $C_k(t)$ represents the costs of owning a vehicle in scenario *k* at year *t*, while $C_0(t)$ represents the costs of owning a vehicle in the baseline scenario *0* at year *t*. Finally *e* is the price elasticity. Litman (2010) summarizes a wide range of price elasticities from the literature. A range of -0.2 to 0 with an average of -0.1 is given for the elasticity between fuel price and car ownership. A price elasticity of -0.1 is used in the SERAPIS fleet model.

Choice model - propulsion technology

As common in Systems Dynamics modelling the development of SERAPIS started with a qualitative analysis using Causal Loop Diagrams. A Causal Loop Diagram consists of entities connected by arrows denoting the causal influences among variables. Entities – in the context of Systems Dynamics – are elements which affect other elements and are themselves affected by other elements. An entity has to represent an unspecified quantity, i.e. it must be possible to make statements whether an entity is increasing or decreasing. Entities are related by causal links, symbolised by arrows. Each causal link is assigned either the characteristic same (+) or opposite (-) which indicates how the dependent entity reacts when the independent entity changes. A causal link of the type "+" means that if the cause increases, the effect increases above what it would otherwise have been, and if the cause decreases, the effect decreases below what it would otherwise have been. A causal link of the type "-" means that if the cause increases, the effect decreases below what it would otherwise have been, and if the cause decreases, the effect increases above what it would otherwise have been. Figure 5 shows as an example the results of the qualitative analysis of what influences the utility of owning an electric vehicle.

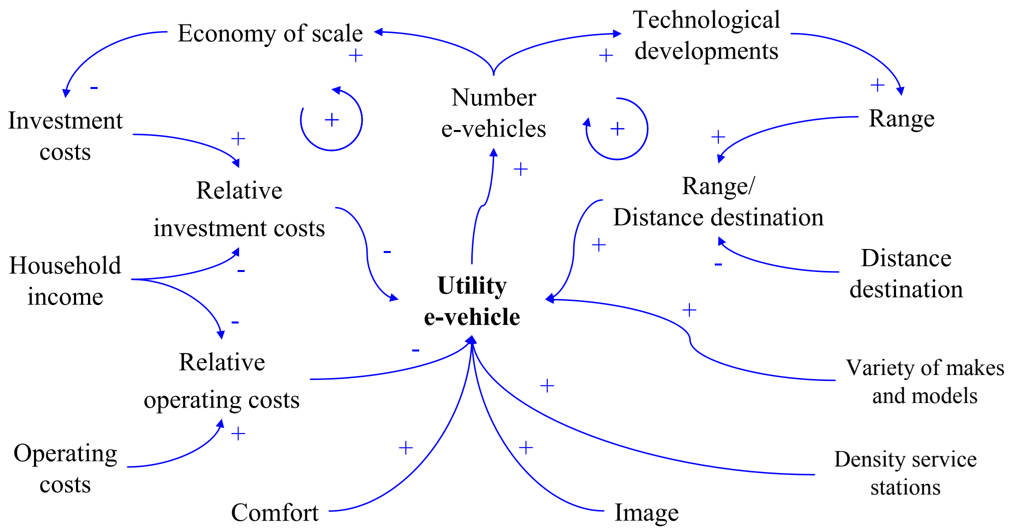


Figure 5: Qualitative analysis utility of e-vehicles

For the quantitative modelling a multinominal logit-model was selected to model the choice of propulsion technology in each model year (Equation 2) (see also, e.g. [1] [4] [13]). The probability P_i that propulsion technology i is chosen is the exponential function of the utility U_i of the choice of propulsion technology i divided by the sum over the exponential functions of all alternatives. At the moment SERAPIS considers the vehicle types car and motorcycle and the propulsion technologies internal combustion engine (ICE), hybrids and battery electric.

$$P_i = \frac{e^{U_i}}{\sum_i e^{U_i}}$$

Equation 2: Basic form of the multinominal logit-model (MNL)

In SERAPIS the utility U_i of propulsion technology i is a function of the investment costs I_i, the operating costs O_i, the variety of makes and models M_i, the density of service stations D_i and the range with a single tank contents or battery load R_i (Equation 3).

$$U_i = f(I_i, O_i, M_i, D_i, R_i)$$

Equation 3: Utility of the choice of a propulsion technology

The utility definition used in SERAPIS is to a large extent based on the model design as presented by Green [13]. The utility U_i of propulsion technology i equals the coefficient for vehicle price μ_P multiplied by the generalized costs C_i of propulsion technology i (Equation 4).

$$U_i = \mu_P * C_i$$

Equation 4: Utility and generalized costs

The coefficient for the vehicle price μ_P is calculated as the ratio of the price elasticity β_P to the purchase price P multiplied by one minus the market share s (Equation 5).

$$\mu_P = \frac{\beta_P}{P*(1-s)}$$

Equation 5: Coefficient for vehicle price

The generalized costs for the variety of makes and models C^M_i is calculated as the ratio of a parameter γ divided by the coefficient for the vehicle price μ_P multiplied by the natural logarithm of the ratio of the number of makes and models n_i for propulsion technology i to the total number of makes and models N (Equation 6). In accordance with Greene [13] the parameter value of γ is defined as 0.67.

$$C_i^M = \frac{\gamma}{\mu_P} * \ln\left(\frac{n_i}{N}\right)$$

Equation 6: Generalised costs variety of makes and models

The generalized costs of the density of the service station network C^D_i is calculated as the ratio of the parameter *C* multiplied by the exponential function of parameter *b* multiplied by the share of service stations s_i selling fuel for propulsion technology *i* to the coefficient for the vehicle price μ_P (Equation 7). In accordance with Greene [13] the parameter values of *C* and *b* are defined as -6.154 and -20.149 respectively.

$$C_i^D = \frac{C * e^{b * s_i}}{\mu_P}$$

Equation 7: Generalised costs network of service stations

The generalized costs for the range C^R_i of propulsion technology *i* are calculated as the ratio of a parameter *K* to the coefficient for the vehicle price μ_P multiplied by the range R_i of propulsion technology *i* (Equation 8). In accordance with Greene [13] the parameter value of *K* is defined as -285.

$$C_i^R = \frac{K}{\mu_P * R_i}$$

Equation 8: Generalised costs range

The combination of Equation 3 to Equation 8 allows the calculation of the total utility of each propulsion technology. The utility U_i of choosing propulsion technology *i* is the coefficient for vehicle price μ_P multiplied by the sum of generalized costs C_i (Equation 9).

$$U_i = \mu_P * \left(C_i^O + C_i^I + C_i^M + C_i^D + C_i^R\right) = \mu_P * C_i^O + \mu_P * C_i^I + \gamma * \ln\left(\frac{n_i}{N}\right) + C * e^{b * s_i} + \frac{K}{R_i}$$

Equation 9: Utility and generalised costs

The electricity demand for e-mobility $E_{bev}(t)$ in year *t* is calculated as the distance travelled per battery electric vehicle and year d_{bev} multiplied by the number of battery electric vehicles $N_{bev}(t)$ in year *t* multiplied by the average electricity consumption of the battery electric vehicle fleet $e_{bev}(t)$ in year *t* (Equation 10). The base year average electricity consumption of the battery electric vehicle fleet $e_{bev}(t)$ has been selected with 18 kWh/100 km [27]. The SERAPIS user has the possibility to define a yearly improvement rate for the energy efficiency of the new battery electric vehicles.

$$E_{bev}(t) = d_{bev} * N_{bev}(t) * e_{bev}(t)$$

Equation 10: Electricity demand for e-mobility

On the supply side SERAPIS calculates the number of small hydro power plants, wind power stations, wood chips power plants and biogas power plants and the square meters of photovoltaic cells which would be necessary to satisfy the demand from e-mobility.

Assumptions for future development in the transport sector

The proportion of pure electric passenger car fleet by 2020 is highly dependent on public subsidies and investments in infrastructure. Because of the expected energy price developments (Figure 2) it is not until 2030 that the number of electrically-powered cars will rise sharply. By 2020, we expect in scenario “Steering,” that assumes massive regulatory and policy intervention, an electric car fleet of around 100,000 vehicles. However, recent experiences in the (non-)implementation of the Austrian Energy Strategy does provide little evidence that this scenario is possible by 2020. Only from 2030 onwards and due to the increasing prices of fossil fuels, the passenger car fleet will rise sharply even without public intervention (Chasing scenario). A detailed description of the assumption can be found in Renner et al. [34].

The following table summarize some of the measures for passenger traffic in the transport system that are assumed in the three scenarios within the model.

Table 4: Description of measures in passenger transport system (annual changes in %)

Area	Indicator	Period	Waiting	Chasing	Steering
Walking and cycling infrastructure	Attractiveness	2010–2020	0,0 %	0,0 %	0,1 %
		2020–2030	0,0 %	0,0 %	0,1 %
		2030–2040	0,0 %	0,1 %	0,2 %
		2040–2050	0,0 %	0,1 %	0,2 %
Investment in the long-distance rail network	Travel speed long-distance	2010–2020	0,8 %	0,8 %	2,0 %
		2020–2030	0,6 %	0,6 %	1,6 %
		2030–2040	0,4 %	2,0 %	1,2 %
		2040–2050	0,2 %	1,6 %	0,8 %
Investment in the regional rail network	Travel speed regional distance	2010–2020	0,4 %	0,4 %	1,6 %
		2020–2030	0,3 %	0,3 %	1,4 %
		2030–2040	0,2 %	1,6 %	1,2 %
		2040–2050	0,1 %	1,4 %	1,0 %
	Density routes and stops	2010–2020	0,0 %	0,0 %	0,2 %
		2020–2030	0,0 %	0,0 %	0,2 %
		2030–2040	0,0 %	0,2 %	0,2 %
		2040–2050	0,0 %	0,2 %	0,2 %
Investment in local public transport	Travel speed	2010–2020	0,3 %	0,3 %	1,1 %
		2020–2030	0,2 %	0,2 %	1,0 %
		2030–2040	0,2 %	1,1 %	0,9 %
		2040–2050	0,1 %	1,0 %	0,8 %
	Density routes and stops	2010–2020	0,0 %	0,0 %	0,5 %
		2020–2030	0,0 %	0,0 %	0,5 %
		2030–2040	0,0 %	0,5 %	0,5 %
		2040–2050	0,0 %	0,5 %	0,5 %
Public transport fares	Fares	2010–2020	0,8 %	0,8 %	-1,7 %
		2020–2030	0,8 %	0,8 %	-1,7 %
		2030–2040	0,8 %	-1,7 %	-1,7 %
		2040–2050	0,8 %	-1,7 %	-1,7 %
Traffic calming urban space	Reducing car speed	2010–2020	-0,4 %	-0,4 %	-1,0 %
		2020–2030	-0,4 %	-0,4 %	-1,0 %
		2030–2040	-0,4 %	-1,0 %	-1,0 %
		2040–2050	-0,4 %	-1,0 %	-1,0 %
Climate change levy on fossil fuels	Cost per vehicle-km	2010–2020	0,0 %	0,0 %	6,0 %
		2020–2030	0,0 %	0,0 %	4,0 %
		2030–2040	0,0 %	2,0 %	2,0 %
		2040–2050	0,0 %	2,0 %	2,0 %

Based on the general assumptions in the three scenarios regarding demographic and socio-economic developments, energy prices, etc. we calculated different paths for total personal transport demand. The development of energy prices has a major impact on the total number of vehicle kilometres in all propulsion technologies.

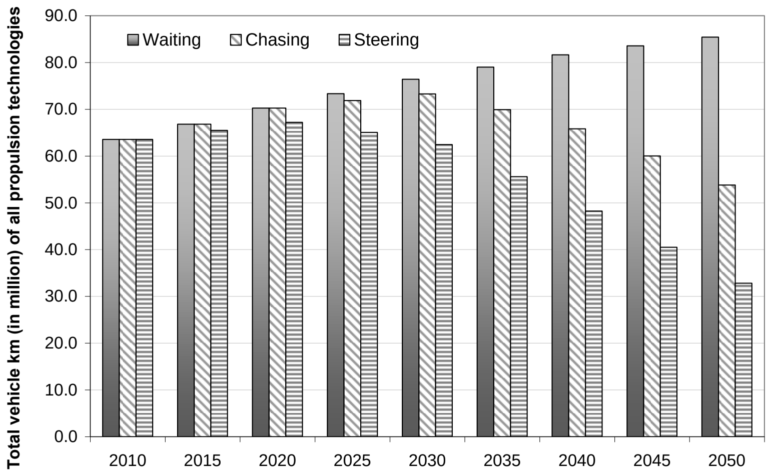


Figure 6: Development of total vehicle km in Austria, 2010-2050

The choice of propulsion technology (internal combustion engine, hybrid, electric) is represented by a multinomial logit-model. The factors that influence the choice of propulsion technologies are investment and operating costs, the density of the service network, variety and range of vehicle models. The following figures summarize relevant milestones in the development of electric vehicles for the scenarios “Chasing” and “Steering” in Austria. In scenario “Steering” we assume massive investments in infrastructure for electric vehicles.

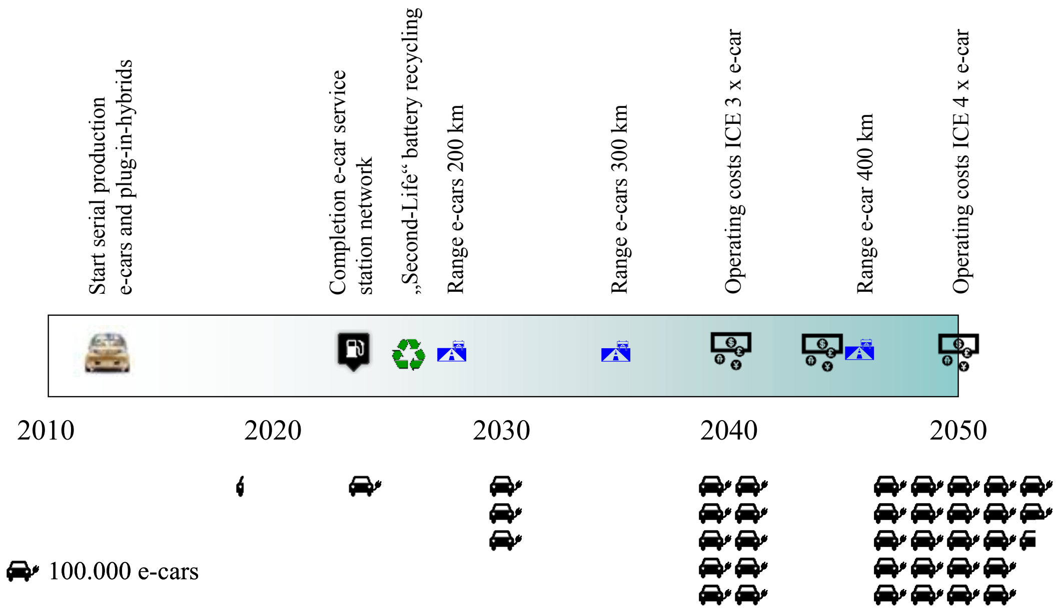


Figure 7: Development of electric car fleet in scenario “Chasing”

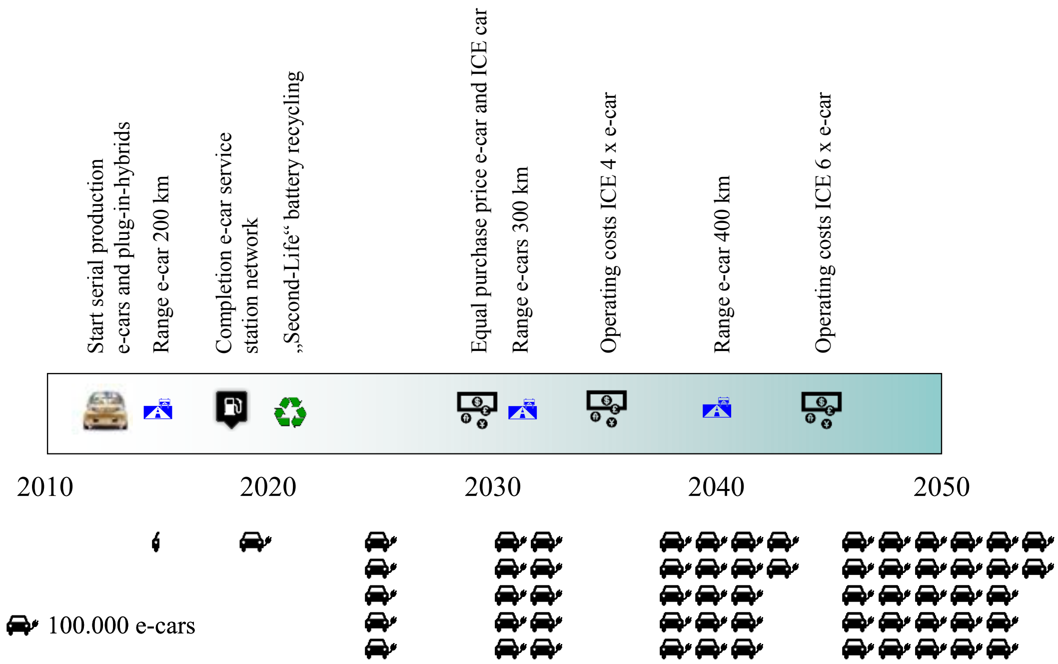


Figure 8: Development of electric car fleet in scenario "Steering"

Consequently, even with similar assumptions about the development of oil prices, in scenario "Steering" we expect a much stronger push for electric vehicles. The share of electric vehicles in the total number of vehicles for the three scenarios is displayed in the following figure. This is also a reflection of the lower number of total vehicle kilometres and number of vehicles in scenario "Steering."

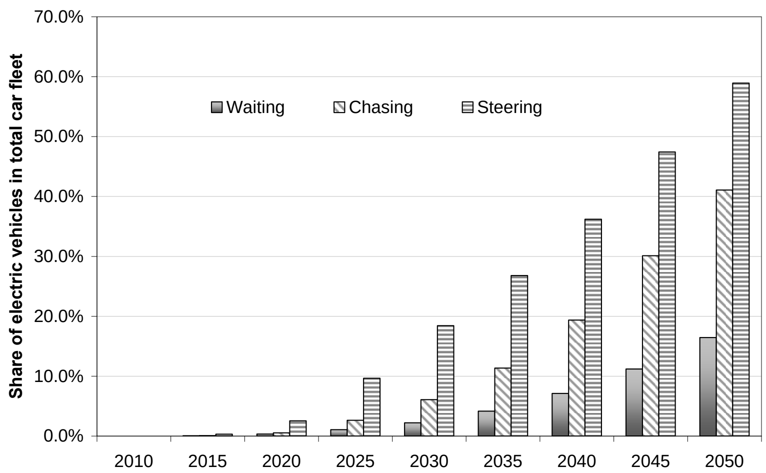


Figure 9: Share of electric vehicle in total vehicle fleet in Austria, 2010-2050

Consequences for final energy and electricity consumption in the transport sector

The increasing use of electric vehicles acts as an important driver for electricity consumption in the transport sector. Based on the development of the vehicle fleet the electricity demand for the three scenarios was calculated (Table 6). However, the maximum share of electricity in final energy consumption in the transport sector is not expected to exceed 30% until 2050 (Table 8).

Without substantial policy measures and only a moderate rise in oil prices we expect a stabilization of final energy consumption in the transport sector with a 10% share of electricity (scenario "Waiting"). However, if a coordinated development of infrastructure for electric vehicles, a substantial climate change levy from 2030 onwards and rising oil prices is assumed (scenario "Steering"), there will be an impact on the costs per vehicle-km, the vehicle fleet and electricity consumption. In that case, total final energy consumption is halved (Table 5).

Table 5: Total final energy consumption in transport sector in PJ, 2010-2050

PJ	2010	2015	2020	2025	2030	2035	2040	2045	2050
Waiting	324.0	329.2	334.5	341.7	343.9	341.3	338.5	330.9	328.8
Chasing	323.9	322.4	318.2	316.8	305.9	284.9	263.2	232.0	205.5
Steering	323.8	318.7	303.6	285.0	249.5	218.7	198.1	172.8	155.8

Table 6: Total electricity consumption in transport in PJ, 2010-2050

PJ	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Waiting	11.8	13.8	17.4	19.7	22.8	25.9	29.1	31.4	32.8
Chasing	11.9	14.9	20.6	24.6	30.7	35.2	39.6	45.2	49.2
Steering	11.9	15.0	22.7	29.0	39.3	43.8	44.8	46.5	46.9

Table 7: Growth of electricity consumption in transport sector in % relative to 2010

%	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Waiting		17%	47%	67%	93%	119%	146%	165%	177%
Chasing		26%	74%	108%	159%	197%	234%	281%	315%
Steering		26%	91%	144%	231%	269%	278%	292%	295%

Table 8: Share of electricity in total final energy consumption of transport sector, 2010-2050

%	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Waiting	4%	4%	5%	6%	7%	8%	9%	9%	10%
Chasing	4%	5%	6%	8%	10%	12%	15%	19%	24%
Steering	4%	5%	7%	10%	16%	20%	23%	27%	30%

Conclusions

Total final energy consumption will decrease within the next 40 years. The strongest decrease in final energy consumption is expected in private households. This decline is mainly due to significant improvements in building envelopes and in the provision of heat. Although the degree of equipment will continue to rise, particularly for the entertainment and communications technologies, higher energy prices and regulatory policies will contribute to limit the specific energy consumption.

However, the share of electricity in total final energy consumption will increase in all sectors. In the Steering scenario, in 2050 more than 30% of total final energy will be consumed in the form of electricity (Figure 10).

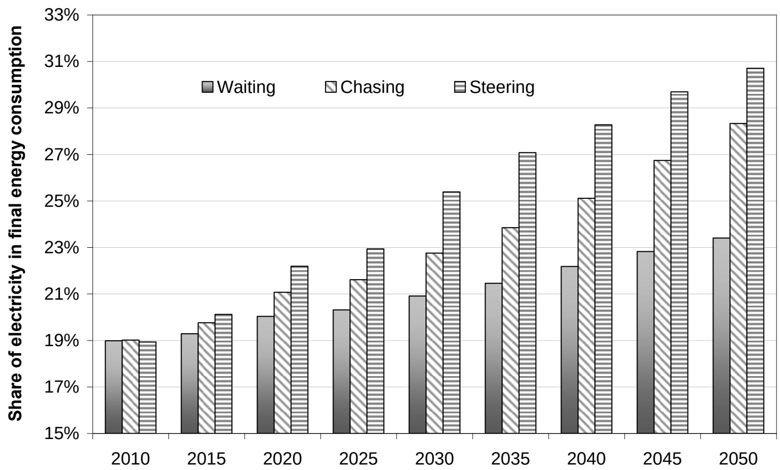


Figure 10: Share of electricity in total final energy consumption, 2010-2050

In the transport sector, the dynamics of oil prices is the crucial variable for the development of final energy consumption. While in the low-price scenario (scenario "Waiting") final energy consumption continues to increase and only slightly decreases from 2030 onwards, in the other scenarios individual mobility will become less affordable. In the Steering scenario, the post-fossil fuel era is anticipated, the fuel tax increases significantly and investments are supported in public transport and electric vehicles.

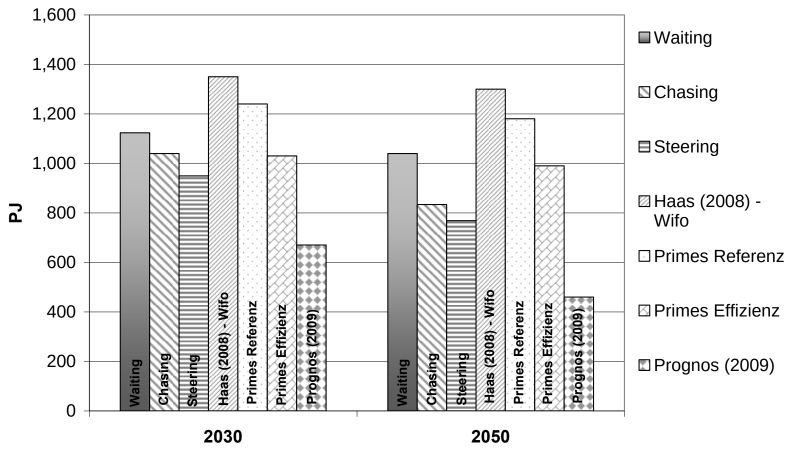
For Austria as a whole, power consumption in absolute terms, unlike final energy consumption, will increase until 2050. The largest increase in power consumption is expected in the transport sector. The power consumption will quadruple by 2050 in the scenarios "Chasing" and "Steering" and amount to about one-fifth of the total electricity consumption. Overall, electricity demand from 2010 to 2050 is expected to increase by around 20%. Table 9 provides an overview of the results.

Table 9: Development of electricity consumption in Austria in GWh, 2010-2050

GWh		**2010**	**2020**	**2030**	**2040**	**2050**
Private households	Waiting	14,105	14,173	14,172	13,973	13,560
	Chasing	14,181	14,185	13,714	13,303	12,665
	Steering	13,924	14,370	13,873	13,318	12,416
Service sector	Waiting	11,716	13,174	13,208	13,195	13,014
	Chasing	11,716	13,074	12,339	10,645	9,335
	Steering	11,716	12,285	12,108	10,755	9,011
Industrial sector	Waiting	27,707	30,019	31,529	31,789	31,931
	Chasing	27,707	30,297	31,140	31,248	29,946
	Steering	27,707	30,009	32,220	33,677	33,698
Transport sector	Waiting	3,289	4,825	6,340	8,081	9,103
	Chasing	3,294	5,733	8,536	11,009	13,671
	Steering	3,298	6,294	10,903	12,451	13,027
Total electricity consumption	Waiting	56,817	62,190	65,250	67,037	67,608
	Chasing	56,898	63,289	65,729	66,205	65,617
	Steering	56,645	62,958	69,103	70,201	68,151

Our results do not differ dramatically from the existing literature (Figure 11). By 2030, Haas et al. [15] expect final energy consumption of 1,350 PJ, and by 2050 (using trend extrapolation) about 1,300 PJ. The Primes scenario of the European Commission expects by 2030 final energy consumption from 1,030 to 1,240 PJ and by 2050 final energy consumption of 990-1,180 PJ. The study by Prognos and Ökoinstitut [33] for Germany expected in 2050 a reduction of final energy consumption by 59%

compared to 2005. If this trend is applied to the situation in Austria, this development would mean final energy consumption of about 670 PJ in 2030 and consumption of about 460 PJ in 2050.



Sources: Own calculations, Haas et al. (2008, 35), Prognos/Ökoinstitut (2009), PRIMES scenario for EC

Figure 11: Comparison of scenario results with the literature

In sum, the results show that electricity will not lose in significance in the decades to come but will, instead, play an important part in the transformation of the economy to a post-fossil age. This is reconfirmed by the International Energy Agency (IEA) which argues that a "decarbonised power supply opens the prospect of increasing demand-side electrification as a zero-emission solution for the long term" [31]. Sustainable, low-risk and low-carbon electricity production will therefore be at the corner stone of a future energy system. Electricity from water, wind and sun, transported and distributed with intelligent grids, will not only provide sufficient energy to fuel demand, as the visionary work by Jackobson et al. suggests [23-24], it will also make Europe more independent from energy imports and thus increase energy security in Europe. This, in turn, not only has major economic advantages compared to other low-carbon but non-sustainable and high-risk forms of energy such as nuclear energy [7-9] [11] [26]. With the focus on renewable electricity production it will also be possible to completely phase out cost-ineffective and hazardous solutions that only perpetuate a non-sustainable energy system.

In the transport sector, the real question and the main challenge is whether the change towards non-fossil forms of propulsion is accompanied in time by corresponding investment in infrastructure and support for market development of vehicles. What we can derive from the scenarios is that strong political leadership is required to pursue the right direction and act rather than react to global developments. This is supported by recent remarks by the European Commission's director-general for transport and mobility, Marjeta Jager, at a conference on peak oil. "If action is delayed," Ms. Jager argued, "in the not-too-distant future we may be forced to drastically reduce all our mobility and import technological solutions from other part of the world." It would be a "fatal mistake" for the EU to postpone measures to reduce oil dependency [39]. Electric vehicles may serve as a substitute to oil, however only if the right measures are taken in time.

References

[1] Achtnicht, M./G. Bühler/C. Hermeling, 2008. Impact of service station networks on purchase decisions of alternative fuel vehicles. Discussion Paper, Zentrum für europäische Wirtschaftsforschung GmbH, Mannheim, ftp://ftp.zew.de/pub/zew-docs/dp/dp08088.pdf.

[2] Aleklett, K./M. Höök/K. Jakobsson/M. Lardelli/S. Snowden/B. Söderbergh, 2010. The Peak of the Oil Age - Analyzing the world oil production Reference Scenario in World Energy Outlook 2008. Energy Policy, 38, 1398-1414.

[3] Anderson, V./L. Johnson, 1997. Systems Thinking Basics - From Concepts to Causal Loops. Pegasus Communications, Inc., Waltham.

[4] Batley, R.P./J.P. Toner, 2003. Hierarchical Elimination-by-Aspects and Nested Logit Models of Stated Preferences for Alternative Fuel Vehicles, European Transport Conference 2003, Strasbourg.

[5] Bertoldi, P./B. Atanasiu, 2009. Electricity Consumption and Efficiency Trends in the Enlarged European Union - Status report 2009. European Commission, Directorate-General Joint Research Centre, Luxembourg.

[6] BMWFJ/BMFLUW, 2010. Energiestrategie Österreich. Bundesministerium für Wirtschaft, Familie und Jugend (BMWFJ), Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMFLUW), Wien, März 2010, http://www.energiestrategie.at/ images/stories/pdf/longversion/energiestrategie_oesterreich.pdf.

[7] Bradford, P.A., 2009. The nuclear renaissance meets economic reality. Bulletin of the Atomic Scientists, (November/December 2009), 60-64.

[8] Cooper, M., 2009. The Economics of Nuclear Reactors: Renaissance or Relapse?, Institute for Energy and the Environment, Vermont Law School, Vermont.

[9] Cooper, M., 2010. Economic Advisability of Increasing Loan Guarantees for the Construction of Nuclear Power Plants. Testimony at the Domestic Policy Subcommittee, Committee on Oversight and Government Reform, U.S. House of Representatives. Washington, 23 March 2010.

[10] Dimitropoulos, J., 2007. Energy productivity improvements and the rebound effect: An overview of the state of knowledge. Energy Policy, 35, 6354–6363.

[11] Findlay, T., 2010. The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation (Nuclear Energy Futures Project). Centre for International Governance Innovation (CIGI), Waterloo, Ontario and Canadian Centre for Treaty Compliance (CCTC) at the Norman Paterson School of International Affairs, Carleton University, Ottawa, Waterloo.

[12] Gates, R.M., 2005. Oil shockwave-oil crisis executive simulation. National Commission on Energy Policy and Securing America’s Future Energy. U.S. National Commission on Energy Policy; Securing America's Energy Future.

[13] Greene, D.L., 2001. TAFV Alternative Fuels and Vehicle Choice Model Documentation. Center for Transportation Analysis, Oak Ridge National Laboratory, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2001_134.pdf.

[14] Haas, R./P. Biermayr, 2000. The rebound effect for space heating. Empirical evidence from Austria. Energy Policy, 28, 403-410.

[15] Haas, R./A. Müller/L. Kranzl, 2008a. Szenarien der gesamtwirtschaftlichen Marktchancen verschiedener Technologielinien im Energiebereich. Endbericht zum gleichnamigen Projekt im Rahmen der Programmlinie "Energiesysteme der Zukunft". Energy Economics Group, Wien.

[16] Haas, R./N. Nakicenovic/A. Ajanovic/T. Faber/L. Kranzl/A. Müller/G. Resch, 2008b. Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies. Energy Policy, (36), 4012–4021.

[17] Herring, H., 1999. Does energy efficiency save energy? The debate and its consequence. Applied Energy, 63, 209-226.

[18] Herring, H., 2006. Energy efficiency—a critical view. Energy, 31(1), 10–20.

[19] Hirsch, R.L., 2008. Mitigation of maximum world oil production: Shortage scenarios. Energy Policy, 36, 881–889.

[20] Hirsch, R.L./R. Bezdek/R. Wendling, 2005. Peaking of World Oil Production: Impacts, Mitigation and Risk Management. Science Applications International Corp.; Report prepared for U.S. Dept. of Energy, February 2005.

[21] Höök, M./R. Hirsch/K. Aleklett, 2009. Giant oil field decline rates and their influence on world oil production. Energy Policy, 37(6), 2262-2272.

[22] Huntington, H.G., 2005. The Economic Consequences of Higher Crude Oil Prices. Report for U.S. Department of Energy. Energy Modeling Forum, Stanford University, Stanford.

[23] Jacobson, M.Z./M.A. Delucchi, 2009. A Path to Sustainable Energy By 2030. Scientific American, (November), 58-65.

[24] Jacobson, M.Z./M.A. Delucchi, fc. 2011. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. Energy Policy, In Press, Corrected Proof, Available online 30 December 2010

[25] Keppo, I./M. Strubegger, 2010. Short term decisions for long term problems – The effect of foresight on model based energy systems analysis. Energy, 35(5), 2033-2042.

[26] Kidd, S., 2008. Escalating costs of new build: what does it mean? Nuclear Engineering International, (22. August 2008).

[27] Klien, 2008. Leitfaden zur Ausschreibung Elektromobilität. Klima- und Energiefonds, Wien, August 2008.

[28] Litman, T., 2010. Transportation Elasticities - How Prices and Other Factors Affect Travel Behavior. Victoria Transport Policy Institute.

[29] Meadows, D.H./J. Randers/D.L. Meadows, 2006. Grenzen des Wachstums. Das 30-Jahre-Update. Signal zum Kurswechsel. Hirzel Verlag, Stuttgart

[30] Naccache, T., 2010. Slow oil shocks and the ‘‘weakening of the oil price-macroeconomy relationship’’. Energy Policy, 38(5), 2340-2345.

[31] OECD/IEA, 2008. Energy Technology Perspectives 2008 - Scenarios & Strategies to 2050. Organisation for Economic Co-operation and Development, International Energy Agency, Paris.

[32] OECD/IEA, 2009. World Energy Outlook 2009. Organisation for Economic Co-operation and Development, International Energy Agency, Paris, I:\World Energy Outlook 2009\weo2009_part1_chut89.pdf

[33] Prognos/Öko-Institut, 2009. Klimaschutz bis 2050: Vom Ziel her denken. Prognos AG / Öko-Institut, Basel / Berlin.

[34] Renner, S./M. Baumann/A. Jamek/B. Lang/P. Pfaffenbichler, 2010. Visionen 2050. Identifikation von existierenden und möglichen zukünftigen Treibern des Stromverbrauchs und von strukturellen Veränderungen bei der Stromnachfrage in Österreich bis 2050. Studie der Österreichische Energieagentur im Auftrag von Österreichs Energie (VEÖ), Wien, September 2010.

[35] Roberts, N./D.F. Andersen/R.M. Deal/M.S. Garet/W.A. Shaffer, 1994. Introduction to Computer Simulation - A System Dynamics Approach. Productivity Press, Portland.

[36] Statistik Austria, 2010. Bevölkerungsschätzung 2010-2050. Wien.

[37] Sterman, J.D., 2000. Business Dynamics - Systems Thinking and Modeling for a Complex World. McGraw-Hill Higher Education.

[38] Umweltbundesamt, 2011. Treibhausgasemissionen 1990-2009, Datenstand 2011. Vienna, 12.01.2011, http://www.umweltbundesamt.at/fileadmin/site/presse/news_2011/THGemissionen2009.pdf.

[39] EurActive, 2011. Act now on peak oil or curtail mobility, says Commission, 04 May 2011, http://www.euractiv.com/en/energy/act-peak-oil-curtail-mobility-commission-news-504506

Promoting energy efficiency and mitigation potentials in the residential and commercial sectors in world regions in 2020

Tatsuya Hanaoka*, Yuko Kanamori, Osamu Akashi, Kazuya Fujiwara, Go Hibino, Yuzuru Matsuoka, and Mikiko Kainuma

**** National Institute for Environmental Studies, Tsukuba, Japan***

Abstract

The objective is to analyze the effects of promoting energy efficiency improvement and estimate technological mitigation potentials and costs considering various options such as cooling, heating, lighting, and hot water in the residential and commercial sectors in world regions by using a bottom-up approach. This study discusses the effects of behavior changes on technology selection, taking into account the settings of a discount rate for investments, and evaluates their effects on the results of mitigation potentials and costs. This study focuses on two major policy instruments for promoting energy efficient technologies: imposing a carbon price and lowering a discount rate for investments.

One important finding is that different assumptions of carbon prices and discount rates for investments have significant impacts on the results of GHG mitigation potentials and costs. In the residential and commercial sectors, the impact of pricing a carbon emission becomes more prominent in developed countries, because energy prices are higher in developed countries than in developing countries; and the impact of lowing a discount rate for investments is relatively larger in developing countries than the impact of pricing a carbon emission, because the effects of energy savings are considered over a sufficiently long period and highly energy efficient technologies with high capital costs become cost-effective even if energy prices are low in developing countries. However, it is necessary to discuss carefully how to change behavior patterns and lengthen the payback period for an actor, for example ESCO (Energy Service Company), low-interest financing, government subsidies and investment in energy-saving technologies, and visualization of energy saving information. In order to achieve a low-carbon society, comprehensive strategies are required to promote mitigation technologies at a low discount rate for investments to enable the achievement of maximum technological mitigation potentials through energy savings.

Introduction

The Fourth Assessment Report (AR4), Working Group III (WG III) by the Intergovernmental Panel on Climate Change (IPCC 2007), pointed out that mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels (see page 15 of the SPM in the IPCC AR4). The IPCC AR4 also indicated that energy efficiency plays a key role in many scenarios for most regions and timescales, but to lower the stabilization levels, these scenarios emphasize the use of low-carbon energy sources, such as renewable energy and nuclear power, and the use of CO_2 capture and storage (CCS) in the long term (see page 16 of the SPM in the IPCC AR4). Thus, especially in the short term (to the years 2020-2030), energy efficiency improvement has an important roles in reducing CO_2 emissions in world regions.

By reviewing past trends, the International Energy Agency (IEA) concluded that total final energy consumption in the IEA 17 countries[1] should have been reduced by around 17 % due to the effects of energy efficiency improvement since 1990 (IEA 2009a). However, based on the IEA report of case

[1] IEA 17 includes Australia, Austria, Canada, Denmark, Finland, France, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, United States.

studies in the residential sectors in major IEA countries such as the USA, the EU, Japan, France, Germany and the UK, final energy demand and CO_2 emissions in the households sector have been increasing rather than decreasing, even though energy efficiency improvement has been increased in the past (IEA 2008). There were various driving forces for the increased energy consumption in the residential sectors, for example the increase in the number of dwellings and the floor area of dwellings, as well as changes in behavior patterns. Lifestyle and behavior changes are an important element in achieving a low-carbon society and changes in lifestyle contribute to GHG emissions reductions across all sectors, most obviously in the residential and commercial sectors. However, it is generally not easy to change lifestyles. For example, regarding purchasing behavior, an actor takes into account the ratio of the risk of exposure to the return on investment of their purchase, and so without some policy pushes in the market, this behavior becomes a barrier to promoting energy efficiency technologies.

It is said that it is often more cost-effective to invest in end-use energy efficiency improvement than in increasing energy supply to satisfy demand for energy services. (See page 13 of the SPM in the IPCC AR4). However, it is important to discuss how cost-effective such investments are and how great the mitigation potentials are in world regions. Thus, this study focuses on analyses of mitigation potentials in the residential and commercial sectors in world regions in 2020, especially 1) assessment of promotion of energy efficiency and technological feasibility in the residential and commercial sectors, 2) estimation of technological mitigation potentials and costs considering various sectors such as cooling, heating, lighting, and hot water in world regions, and 3) evaluation of behavior changes on technology selection by considering different settings of a discount rate for investments (i.e. payback-period) and their effects on the results of mitigation potentials and costs.

Methodology

This study used the detailed technology options database developed in the AIM/Enduse [Global] model which is a bottom-up optimization model. This model covered 32 of the world's geographical regions, which can be also aggregated into Annex I and Non-Annex I, and this study focused on major GHG emitting countries/regions such as the USA, the EU, China, India and Japan. With regard to target gases and sectors, this model covered six GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) regulated under the Kyoto Protocol in multiple sectors such as power generation, industry, residential, commercial, transportation, agriculture, municipal solid waste, industrial processing including fluorocarbons emissions, and fuel mining. In the residential and commercial sectors, various technology options were taken into account such as cooling, heating, lighting, and hot water. Based on a bottom-up approach by using a database of mitigation options which are realistic and currently existing technologies, mitigation potentials and costs were analyzed under various data settings.

Overview of the model structure

Figure 1 shows the overall structure of the models used in this study. In previous studies by Hanaoka, et al. (2009), the models covered 21 geographical world regions, and service demands in each sector were set exogenously based on various kinds of international statistics and outlooks. However, this study extended regional coverage and target sectors, and service demands were estimated using the original models developed for this study in order to conduct consistent analysis. In order to evaluate GHG emissions and mitigation technology options, it was first necessary to estimate the future service demands in each service in this study. Thus, the study consists of three parts: a macroeconomic model, a service demand model, and a technology bottom-up model. Using the macroeconomic model, macroeconomic indicators such as GDP and sector-wise value added were estimated, and based on these socio-economic indicators, service demands in each sector were estimated using various service demand models. Therefore, the socio-economic assumptions such as GDP and population were consistent among all of the sectors and regions in this study. Next, GHG emissions and mitigation potentials for each sector were estimated by using a bottom-up approach with a detailed technology options database. In the bottom-up approach, technology options were selected to satisfy the estimated service demands that were set by the various service demand models, and GHG emissions and final energy demands in the final demand sectors were estimated. The estimated final energy demands were then used to estimate GHG emissions and primary energy supply in the power generation sector.

This study defined “a service” as “a measurable need within a sector that can be satisfied by supplying an output from a device,” and it can be defined in either tangible or abstract terms. Thus, “service demand” refers to the quantified demand created by a service. In other words, a service output from a device satisfies the service demand. For example, in the residential and commercial sectors in this study, service demands include the demand for heating and lighting energy, which are the final output of appliances. It must be noted here that the concepts of ‘final service’ and ‘intermediate service’ are defined for convenience in this study, and may not necessarily imply real-life interpretations of ‘service’.

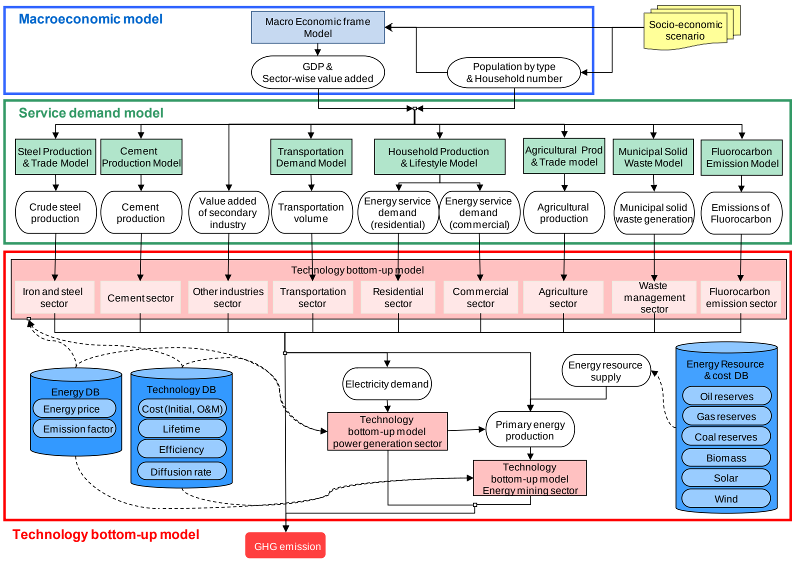


Figure 1 Overview of the model structure

Definitions of mitigation potentials and abatement costs

According to the IPCC AR4 (2007), a baseline is defined as “the reference from which an alternative outcome can be measured, for example, a non-intervention scenario is used as a reference when analyzing intervention scenarios” and mitigation potentials are defined as “the scale of GHG reductions that could be achieved, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced).” This study accepts this definition, but there are various ways of setting a non-intervention scenario. It is important to note that the mitigation potentials and their costs vary depending on the baseline settings as well as key data settings, such as technology data and future energy prices. In this study, the baseline was set for a frozen technology level, which was sometimes used in the bottom-up analyses described in some of the papers reviewed by the IPCC AR4 (2007), and the future share and energy efficiency of the standard technologies in the baseline were fixed at the same levels as those for the base year. Therefore, in this study, mitigation potentials are evaluated as “the reduction amounts that are estimated by comparing the effect of introducing new mitigation technologies to the standard technologies that are fixed at the base-year level, in terms of the target year, target region and target sector.” Then, mitigation costs are estimated as “the additional costs comprising the sum of capital costs (i.e. fixed cost) and operational costs, including energy and running costs, that are required to introduce new mitigation measures as compared to the baseline.”

The mitigation potentials and their abatement costs were estimated using a detailed technology options database developed for the AIM/Enduse[Global] model. Based on the database, the abatement cost curve in target year (t), target region & sector (i) and service type (j) is described as follows. First, the GHG emission reductions per unit of service supply j of a device l, $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$, the additional cost per unit of device l compared to the stock average device in the baseline, $\Delta\hat{C}_{l,i}^{t}$, and the maximum potential stock of device *l*, $\Delta S_{l,i}^{\max,t}$, in time period (year) *t* were calculated. Next, the abatement cost curve was calculated by noting that the abatement costs of a unit reduction, $\Delta \hat{C}_{l,i}^{t} \big/ \Delta \hat{Q}_{l,i}^{t,GHG}$, were plotted along the y-axis, and the accumulated reduction of GHG emissions for device *l*, $\Delta \hat{Q}_{l,i}^{t,\mathrm{GHG}}$, were plotted along the x-axis in the order of ascending abatement cost per unit reduction. $\Delta \hat{Q}_{l,i}^{t,\mathrm{GHG}}$, $\Delta \hat{C}_{l,i}^{t}$, and $\Delta S_{l,i}^{\max,t}$ represent the differences between the respective values in time period *t* and the baseline (i.e., frozen technology in this study). The suffixes of the indices and sets are defined as follows; *i*: region & sector, *j*: service type, *k*: energy type, *l*: energy device (i.e. technology option), *m*: gas type, *t*: time period (year), 0: base year, and $\hat{}$: quantity per unit[2]. As there are various technology options and scales in different sectors and regions, the abatement cost of each mitigation option varies widely. Sometimes, the abatement cost can show a negative net value because a given technology may yield enough energy cost savings to more than offset the costs of adopting and using the baseline technology.

$$\Delta \hat{Q}_{l,i}^{t,GHG} = \sum_{m} GWP_m \cdot \left(\frac{Q_{j,i}^{0,m}}{D_{j,i}^{0}} - \frac{\hat{e}_{l,i}^{t,m}}{\hat{A}_{l,j,i}^{t}\left(1+\psi_{j,i}^{t}\right)} \right) \qquad (1)$$

$$\Delta \hat{C}_{l,i}^{t} = \frac{C_{l,i}^{0}}{D_{j,i}^{0}} - \frac{\hat{C}_{l,j}^{t} \cdot (1+\Lambda_{l,i}^{t})}{\hat{A}_{l,j,i}^{t} \cdot (1+\psi_{j,i}^{t})} \qquad (2)$$

$$\Delta S_{l,i}^{\max,t} = \frac{\Delta D_{l,j,i}^{t} \cdot \theta_{l,j,i}^{t} \cdot (1+\Lambda_{l,i}^{t})}{\hat{A}_{l,j,i}^{t} \cdot (1+\psi_{j,i}^{t})} \qquad (3)$$

$$\Delta Q_{pot,l,i}^{t,GHG} = \Delta \hat{Q}_{l,i}^{t,GHG} \cdot \Delta D_{l,j,i}^{t} \qquad (4)$$

where

$\hat{A}_{l,j,i}^{t}$: Supplied quantity of service *j* per unit operation of device *l* in region & sector *i* in time period *t*.

$\hat{C}_{l,i}^{t}$: Annual cost per unit operation of device *l* in region & sector *i* including the initial cost, energy costs, and maintenance costs, in time period *t*

$C_{j,i}^{t}$: Annual cost of supplying service *j,* including the initial cost, energy costs, and maintenance costs, in time period *t*

$\Delta D_{l,j,i}^{t}$: Maximum service demand for service *j* by recruited device *l* in region & sector *i*

$D_{j,i}^{t}$: Service demand for service *j* in region & sector *i* in time period *t*.

$\hat{e}_{l,i}^{t,m}$: Emissions of gas *m* per unit operation of device *l* in region & sector *i* in time period *t.*

$Q_{j,i}^{t,m}$: Emissions of gas *m* per unit of supplied service *j* in region & sector *i* in time period *t*

$1+\Lambda_{l,i}^{t}$: Operating rate of device *l* in region & sector *i* in time period *t*.

$\psi_{j,i}^{t}$: Supply efficiency of service *j* in region & sector *i* in time period *t.*

---

[2] For some parameters, this indicates quantity per unit of device, while for others, quantity per unit of energy use.

$\theta^{t}_{l,j,i}$: Maximum share of device *l* for service *j* in region & sector *i*

GWP_m : Global warming potential of gas m emissions per unit. (This study takes into consideration the GWP values[6] used in the GHG national inventory reports as stipulated in the Kyoto Protocol.)

Assumptions for energy demands in the residential and commercial sector

Socio-economic data are important key drivers for estimating service demands. In this study, the population growth in 32 regions was set based on future prospects using a medium variant of the UN World Population Prospects (2008), which showed observed population changes from 1950 to 2005 and estimated the future populations of 218 countries up to 2050. As for GDP growth, future GDP and sector-wise value added were estimated by the Socio-economic Macro Frame model, using future population as an input, in order to correlate values with the assumptions for future GDP growth rates in major regions based on a survey of international and national statistics and outlooks. Energy prices are another important factor for estimating mitigation costs and must be set exogenously in this study. Current international energy prices were set based on IEA Energy Prices and Taxes (IEA 2010), and future international energy prices in the mid-term were set based on IEA World Energy Outlook (IEA 2009b). In this study, detailed domestic energy prices needed to be set by fuel type, sector, and country. Thus, future energy prices by fuel type, sector, and country were set under the assumption that domestic energy prices will rise as international energy prices rise.

In the residential and commercial sectors, energy services and energy types were set as follows:

- Energy type: coal, biomass, natural gas, kerosene, LPG, geothermal, solar (including solar heat and solar light), electricity, and heat.
- Energy service type: warming, cooling, hot water, cooking, lighting, refrigerator, TV(only for residential sector), and others.

Energy demands in this study were defined as equation (5), which explains the relation between total energy consumption and energy consumption per unit in the unit of ton of oil equivalent (toe).

$$Energy\ demands\ of\ service\ type\ i = \frac{Energy\ consumption}{Energy\ consumption\ per\ unit\ of\ energy\ service\ i} \quad (5)$$

Energy consumptions by region, by sector, by energy type and by service type in the base year were based on IEA Energy Balance Table (IEA, 2009c, 2009d) data. However, in the Energy Balance Table, the “other sector” category included data for residential, commercial, agriculture, fishing, and non-specified sectors. In this study, these non-specified data were disaggregated into certain sectors by using the methodology of the OECD development center (OECD 1998) and balancing several international statistics, and the energy balances were adjusted for the base year 2005. The energy consumption in 2020 by sector was estimated based on the time-series data, and the ratio of energy consumption by energy type and by service type was set based on SAGE (USDOE, 2003) and World Energy Outlook (IEA, 2009). Energy consumption by region, by sector, by energy type and by service type in 2020 was then estimated using these data sets. To estimate energy consumption by sector, various parameters were determined based on the regression analysis method using time series data for GDP and population from 1971 to 2005.

Table1 Energy service demands in the residential and commercial sectors in major countries

Category	Year	Unit	Japan	USA	EU27	China	India	Russia	Global
Energy demands in residential & commercial	2005	Mtoe	173.6	861.3	937.2	357.6	134.2	271.1	3728.5
	2020	Mtoe	190.6	997.0	1040.6	563.6	199.5	317.5	4689.0
	CAGR	%/yr	0.6%	1.0%	0.7%	3.1%	2.7%	1.1%	1.5%

Note) Growth rate of each service demand is indicated by Compounded Annual Growth Rate (CAGR)

Mitigation technology options in the residential and commercial sector

GHG mitigation potentials were estimated using a detailed technology options database including information on capital costs, operation and management costs, lifetime, energy types, energy efficiency, etc., that contains approximately 500 to 600 mitigation technologies for all sectors. Examples of mitigation technology options in the residential and commercial sectors considered in this study are listed in Table 2. It is important to note that this study was based on realistic and currently existing technologies and did not take into account innovative technologies that may or may not appear by 2020. In addition, local-scale technologies or systems such as Building Energy Management System (BEMS) and Home Energy Management System (HEMS) were not considered due to the limitations of global scale modeling. Mitigation options for buildings such as thermal insulation and central heating systems may have the co-benefits of CO_2 emissions reductions as well as other benefits. However, this study focused on the effects of reducing CO_2 emissions and did consider other benefits because these benefits fluctuate due to various factors and were outside the scope of this study.

Table2 List of technology options in the residential and commercial sectors

Category	Technology options
Cooling	Air conditioner (level 1 – 4)
Warming	Air conditioner (level 1 – 4), Stoves [biomass, coal, kerosene, LPG, Gas], Insulation (level 1 – 5),
Hot water	Water heater [biomass, kerosene, LPG, gas], Water heater (level 1 – 2) [coal], Latent heat recovery water heater [kerosene, LPG, gas], Electric water heater,CO2 refrigerant heat pump water heater, Solar thermal water heater
Cooking	Cooking stove [biomass], Cooking stove (level 1 – 2) [coal, kerosene, LPG, gas], Electric IH cooker (level 1 – 2)
Lighting	Kerosene lamp, Incandescent lamp, Fluorescent bulb lamp (level 1 – 2), Fluorescent lamp (level 1 – 3)
Refrigerator	Refrigerator (level 1 - 4)
TV	TV (level 1 – 4)
Others	Other devices (level 1 – 4)

Case settings for promoting energy efficient technologies

Several policy measures are conceivable for promoting energy efficient technologies on the demand side. Generally in a bottom-up model, it is assumed that an actor behaves in a rational manner to minimize their costs, therefore a cost minimization method is applied, as in this study. The incremental costs of capital investments are compared with the operational costs of energy savings in order to determine whether mitigation technology is adopted or rejected. If a certain mitigation technology achieves sufficient operational costs of energy savings compared to a conventional technology and has a greater cost advantage than the incremental costs of capital investments, the mitigation technology is selected by an actor instead of a conventional technology. The concept of operational costs of energy savings is explained as shown in equation (6).

Costs of energy savings = [amount of annual energy savings by energy type ×

(energy price by energy type＋ emission factor by energy type × carbon price)] × payback period (6)

Thus, in a bottom-up analysis, it is appropriate to analyze the following three major policy instruments: 1) controlling energy prices by policy, 2) imposing a carbon price on energy consumption, and 3) extending the payback period or lowering the discount rate for investments in order to promote a technology that has a high investment risk but offers high energy conservation. In this study, no policy analysis of energy prices was performed as this was outside the scope of the study, because future energy prices will fluctuate due to various factors such as the international trade of energy resources and domestic policies on energy security. Thus, this study focused on the effects of the other two major policy instruments: imposing a carbon price and lowering the discount rate for investments.

Assumptions concerning the discount rate for investments

How to determine mitigation options is an important decision-making issue for an actor, and there are several evaluation approaches available, such as the Net Present Value (NPV) Method, the Internal Rate of Return (IRR) Method, the Payback Period Method, and the Discounted Payback Period Method. It depends on modelers or agencies how they develop a bottom-up type model; some directly set payback periods in a model, others consider payback periods indirectly and set a discount rate for investments which corresponds to an internal rate of return (IRR). The payback period represents the period of time required for the return on an investment, such as in energy savings, to break even in terms of capital cost. In general, a bottom approach for GHG mitigation analysis sets the payback period or the discount rate for investments as a comparative criterion for assessing the cost-effectiveness of mitigation measures, which is one of key factors influencing the results of technology selections.

In this study, mitigation costs comprise capital cost and operational cost, as shown in Equation (7). The capital cost is converted into the annual investment cost required to recruit one unit of a device by using a capital recovery factor, as shown in Equation (8), while the operational cost is the annual cost incurred in operating one unit of a device. The capital recovery factor in Equation (8) converts a present value into a stream of a constant annual value over a specified time at a specified discount rate. An inverse value of this capital recovery factor represents the payback period, meaning that this study takes the payback period into account indirectly by setting a discount rate for investments. For example, if a 33% discount rate for investments is set for a large-scale plant whose average lifetime is estimated as a 30 year-lifetime, then based on Equation (8) the payback period will be around three years. Thus, in this study, the annualized costs of mitigation options are calculated using Equation (7); the additional annual cost per unit of service is calculated using Equation (2); and mitigation options are determined by comparing the cost-effectiveness of each mitigation option.

$$\hat{C}_{l,i}^{t} = \hat{B}_{l,i}^{t} \cdot (1 - SC_{l,i}) \cdot \frac{\alpha_i (1+\alpha_i)^{T_{l,i}}}{(1+\alpha_i)^{T_{l,i}} - 1} + \frac{\hat{g}_{0,l,i}^{t} + \sum_k \hat{g}_{1,k,i}^{t} \cdot \left(1 - \xi_{k,l,i}^{t}\right) \cdot \hat{E}_{k,l,i}^{t}}{1 + \Lambda_{l,i}^{t}} \quad (7)$$

$$\left[P \rightarrow M\right]_T^{\alpha} = \frac{\alpha (1+\alpha)^T}{(1+\alpha)^T - 1} \quad (8)$$

where

$\hat{B}_{l,i}^{t}$: Fixed cost of energy device *l* in region/sector *i* in time period *t*

$SC_{l,i}$: Subsidy rate of energy device *l* in region/sector *i*.

α : Discount rate for investments

$\hat{g}_{0,l,i}^{t}$: Operating cost per unit operation of energy device *l*, other than fuel cost in time period *t*.

$\hat{g}_{1,k,i}^{t}$: Price of energy *k* per unit consumption in time period *t*

$\xi_{k,l,i}^{t}$: Energy saving ratio due to maintenance and improvement of usage of energy *k* by energy device *l* in region/sector *i* in time period *t*.

$\hat{E}_{k,l,i}^{t}$: Consumption of energy *k* by energy device *l* per unit operation in time period *t*.

$T_{l,i}$: Lifetime of energy device *l* in region/sector *i*.

Mitigation costs vary with different settings for the discount rate for investments. The discount rate for investments represents the ratio of the risk exposure to the return on investment, which is an important indicator for an actor. There would be a range of setting discount rates by sector, including sector-specific risk, and by country, including country-specific risk. For example, a high discount rate (i.e. short payback period) is obviously preferable to a low discount rate (i.e. long payback period), especially for private industries and actors that assume a high risk for investing in energy conserving technologies. In other words, the payback period will be much shorter than the lifetime of the technology in question. There is little policy incentive for mitigation technologies at a low discount rate for investments (i.e. long payback period). This is justified by the risk of the investments; however, this lack of incentive becomes a barrier to promote energy efficiency technologies, and so it is difficult to expect the technologies to be sufficiently effective to reduce energy consumption and CO_2 emissions. In order to achieve a low-carbon society, it is necessary to take into account comprehensive strategies to promote mitigation technologies at a low discount rate for investments to achieve the maximum potentials of energy savings.

This study assumed a discount rate for investments as shown in Table 3. The discount rate for investments was determined as follows, by considering assumptions for payback periods.

- The Energy Conservation Center, Japan (ECC 1998) conducted a questionnaire survey of all sectors and reported that the average payback period was 4.4 years across sectors. In addition, a questionnaire survey of companies and households in Japan that was implemented in relation to this study showed that the payback period for investment on an energy saving technology was about three years. There is more of a technology perspective in the short term and the rate of technology improvement is high in the residential, commercial and transport sectors; thus this study assumed in the HDR-RC case that private actors prefer to choose the high discount rate for investments of 33%, which corresponds to an approximately three year payback period.

- This study focused on the effects of setting different levels for discount rates for investments in the residential and commercial sector. The study assumed that many actors become conscious of environmental issues when they are highly public-minded and social-minded and there are circumstances for promoting environmental policies actively. For example, several options are conceivable, such as the promotion of ESCO (Energy Service Company), low-interest financing, government subsidies and investment in energy-saving technologies and visualization of information about energy consumption and CO_2 emissions when the selected technology is used. Thus, this study assumed that, with policy pushes or changes in behavior patterns, actors tend to attach importance to technologies with sufficient energy savings in a long payback period, and the low discount rate for investments was set at 5%, which corresponds to about 50-70% of the technology’s lifetime, in the residential and commercial sectors in the case of LDR-RC.

- The power generation sector is considered to be a kind of public industry that takes into account low investment risks by considering governmental supports. Moreover, facilities with long lifetimes, such as industrial plants and public transportation (trains, ships, aircraft), tend to have a longer payback period. For example, most CDM (Clean Development Mechanism) projects related to facilities with long lifetimes used internal rate of return (IRR), which corresponds to the discount rate for investments, as an evaluation indicator for investments. Most CDM projects set a benchmark rate for IRR of around 8-10% (IGES 2010). Thus, for these sectors, this study set the mid-level discount rate for investments at 10%, which corresponds to an approximately 9-10 year payback period under the assumption of a 30 year lifetime for facilities.

- The features of non-energy sectors differ from those of energy-related sectors. In these sectors, there is less of a technology perspective in the short term and the rate of technology improvement is relatively slow compared to energy-related sectors. The risk for investments should be lower and the payback period is assumed to be long enough to consider the lifetime of technology options. Thus, this study set the discount rate for investments at 5%, referring to the close level of interest rates for national bonds in major countries.

In developing countries and economies in transition (EIT), the economy is unstable and the investment risk is very high, so the annual discount rate for investments would be larger than in other countries. Moreover, values and the perception of economic stability vary across countries, so the valuation standards for the annual discount rates should vary across regions. However, in order to simplify discussions on estimated results, it is important to note that this study did not take into account the country risks when evaluating the mitigation potentials of each region, and the same annual discount rates were assumed across the world.

Table3 Settings for the discount rate for investments

Case name	Sector	Discount rate	Example of payback period (Lifetime of technology)
HDR-RC (High discount rate in residential & commercial)	Residential Commercial Transport	33%	Home appliance: 3 years (10-15years) Car, truck, bus: 3 years (8-12 years)
	Power plant Industry plant Infrastructure House insulation	10%	Power plant: 9-10 years (20-40 years) Industrial plant: 9-10 years (30 years) Train, ship, aircraft: 8-9 years (20 years) Insulation housing: 9-10 years (30years)
	Non-energy sectors (Agriculture, Waste, Fluorocarbons, etc)	5%	Agriculture: 1-11 year (1-15 year) MSW: 10-16 year (15-30 year) Fluorocarbons: 1-13 year (1-20year)
LDR-RC (Low Discount Rate in residential & commercial)	All sectors (except below)	Same as HDR-RC case	
	Residential Commercial	5%	Residential equipments: 7-10 years (10-15years)

Assumptions concerning carbon price

In the current situation, there are several frameworks to take into account carbon pricing, such as emissions trading, CDM and carbon tax. By using the technology options database developed in the AIM/Enduse [Global] model, this study can analyze the effects of pricing a carbon emission but cannot differentiate its framework. Thus the study focused on analyzing the effects of imposing a carbon price.

With regard to the current trend of pricing a carbon emission, useful references are the EUA (European Unit of Accounting) price of the EU-ETS (European Union Emissions Trading Scheme) and the CER (Certified Emission Reduction) price for CDM projects. In the past, EU-ETS carbon prices fluctuated due to global economic change, and varied around 15-30 EURO/tCO_2. The price of CER for CDM projects also fluctuated and varied around 10-20 EURO/tCO_2, which was lower than the EU-ETS price because CER was traded according to project base but not in the market and included various other risks related to CDM projects. As for a carbon tax, some countries such as England, Germany and countries in northern Europe have already imposed a carbon tax. However, this tax is not calculated based on the unit of carbon emissions but the unit of calorific value or amount of material; thus this was not a useful reference for setting a carbon price.

A future carbon price will vary due to various factors, but it is outside the scope of this study to forecast future prices based on economics. Thus, this study simply focused on the effects of carbon pricing, and a future carbon price was set for two cases: Case 1, a carbon price at 50 US$/t$CO_2$, a little more expensive than the EU-ETS market; Case 2, a carbon price double that of Case 1, at 100 US$/t$CO_2$, which is close to the value of penalty charges at 100 EURO/tCO_2 in the EU-ETS market.

Table 4 Settings for carbon prices in 2020

Case name	Carbon prices in 2020
CP50	Pricing a carbon emission at 50 US$/t$CO_2$ across all sectors
CP100	Pricing a carbon emission at 100 US$/t$CO_2$ across all sectors

Overview of scenarios

This study analyzed four scenarios as shown in Table 5, taking into account the effects of pricing a carbon emission and changing the discount rate for investments as shown in Table 3 and Table 4. By comparing the results of Scenarios 1 and 3, or Scenarios 2 and 4, the effects of a carbon price on mitigation potentials and costs across all sectors can be analyzed, showing a sensitivity analysis of a carbon price under the same discount rate settings. In contrast, by comparing Scenarios 1 and 2, or Scenarios 3 and 4, the effects of setting different levels for discount rates for investments in the residential and commercial sectors can be analyzed, showing a sensitivity analysis of changes in lifestyle and behavior in the residential and commercial sectors under the same carbon price settings.

Table5 Scenario settings

	HDR-RC	LDR-RC
CP50	Scenario 1	Scenario 2
CP100	Scenario 3	Scenario 4

Results and discussion

Different assumptions for a carbon price and a discount rate for investments have a significant impact on the results of GHG mitigation potentials and costs. Figure 1 shows GHG abatement cost curves[3] across all sectors under different scenarios in major countries in 2020. Table 6 shows CO_2 emissions[4] in the residential and commercial sectors under different scenarios in major countries in 2020, in order to highlight the effects of pricing a carbon emission and changing the discount rate for investments.

In general, technologies with high capital costs offer greater energy conservation but have a longer payback time than those with low capital costs. Thus, under a high discount rate for investments (i.e. short payback period), technologies with a low investment risk whose energy efficiency is not sufficiently high are selected; thus the incremental cost for reducing CO_2 is high and the mitigation technology is not expected to achieve sufficient reduction effects. On the other hand, under a low discount rate for investments (i.e. long payback period), the effects of energy savings are considered over a long period; thus the incremental cost for reducing CO_2 is lower and the technology is expected to achieve more reduction effects.

Comparing results in developed and developing countries, the impact of pricing a carbon emission and of changing the discount rate for investments differs depending on socio-economic features in each country, as shown in Figure 1. With regard to pricing a carbon emission in the residential and commercial sectors, the impact is larger in developed countries, as shown in Table 6, because energy prices are higher in developed countries than in developing countries. If energy prices are low, the costs of energy savings are also low; thus highly energy efficient technologies with high capital costs do not become cost-effective and they are not selected by an actor. With regard to changing the discount rate for investments, the impact of lowing discount rates is relatively larger in developing countries than the impact of pricing a carbon emission around 50-100 US$/t$CO_2$, because the effects of energy savings are considered for a sufficiently long period and highly energy efficient technologies with high capital costs become cost-effective even if energy prices are low in developing countries.

One caveat is that this study was based on a bottom-up analysis; thus it did not take into account the spillover effects of the introduction of mitigation measures, such changes in industrial structure, service demand, technology costs and energy prices. It is also important to note that the baseline GHG emissions in 2020 were estimated based on the technology-frozen case, which did not take into account changes in the industrial structure. Thus reduction potentials may be overestimated. On the other hand, due to the lack of data availability, some mitigation options such as HEMS, BEMS were not considered; thus by collecting more comprehensive international data, reduction potentials are expected to be further. Another important point to note is that this study shows reduction potentials under the no regret case; however, such mitigation options cannot be introduced without imposing initial costs. As there would be certain mitigation technologies existing in developed countries but not in developing countries, international cooperation towards technology transfers and financial assistance to developing countries may play an important role.

---

[3] These figures do not represent marginal abatement curves but abatement cost curves, which show combinations of reductions of each mitigation technology compared to the baseline and its mitigation costs under a certain carbon price which represents a marginal cost, i.e. the marginal cost of 50 and 100 US$/t$CO_2$.

[4] CO_2 emissions from the power sector are allocated to each sector in proportion to the amount of electricity consumption in each sector. Thus, it includes both direct and indirect emissions.

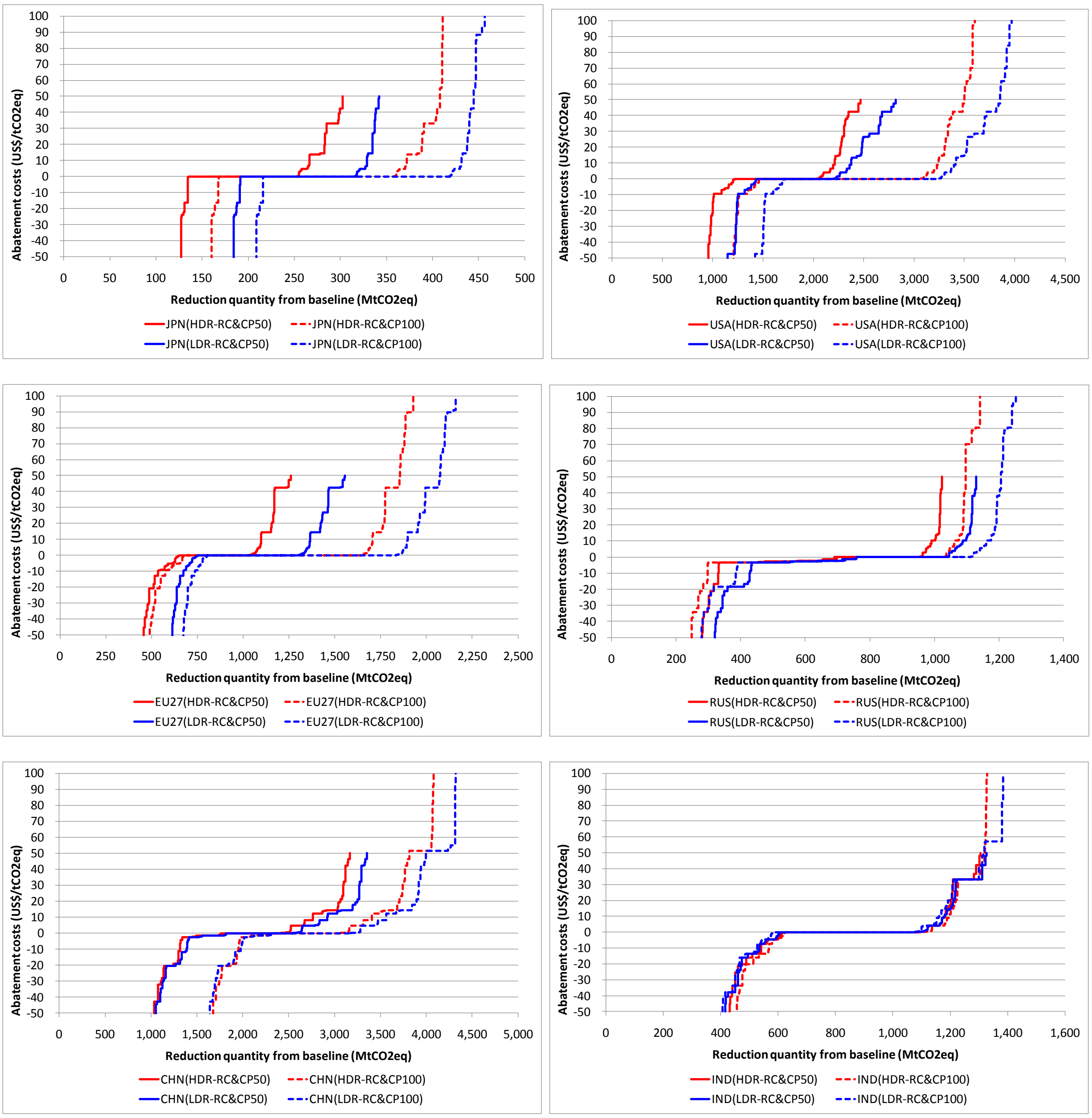


Figure 2 GHG abatement cost curves across all sectors in major countries in 2020

Table6 CO_2 emissions in the residential and commercial sectors in major countries in 2020

Scenario		Japan	China	India	USA	EU27	Russia	Global
CO_2 emissions in the residential and commercial sectors [unit : $MtCO_2$ eq]								
1	HDR-RC&CP50	319.3	1378.5	267.6	2102.1	1349.0	473.8	7998.8
2	LDR-RC&CP50	282.0	1233.8	252.6	1749.5	1096.5	390.1	6815.2
3	HDR-RC&CP100	249.6	1131.1	259.1	1336.4	1007.7	415.9	6339.8
4	LDR-RC&CP100	209.5	969.8	219.4	1006.5	804.6	342.5	5149.1
Differences between scenarios [unit : $MtCO_2$ eq]								
Scenario1 - Scenario3		69.7	247.4	8.5	765.7	341.2	57.9	1659.0
Scenario2 - Scenario4		72.5	264.0	33.2	743.0	291.9	47.6	1666.1
Scenario1 - Scenario2		37.2	144.7	15.0	352.6	252.5	83.7	1183.6
Scenario3 - Scenario4		40.1	161.3	39.7	330.0	203.1	73.4	1190.7

Conclusions

Mitigation measures of energy efficiency improvement on the demand side have an important role in reducing GHG emissions. Several policy measures are conceivable for promoting energy efficient technologies, and this study focused on the effects of two major policy instruments: imposing a carbon price and lowering the discount rate for investments. One important finding is that different assumptions of a carbon price and the discount rate for investments have a significant impact on the results of GHG mitigation potentials and costs. In the residential and commercial sectors, the impact of pricing a carbon emission is larger in developed countries, because energy prices are higher in developed countries than in developing countries; and the impact of lowing a discount rate for investments is relatively larger in developing countries than the impact of pricing a carbon emission, because the effects of energy savings are considered for a sufficiently long period and highly energy efficient technologies with high capital costs become cost-effective even if energy prices are low in developing countries. However, it is necessary to discuss carefully how to lengthen the payback period for an actor; several options are conceivable, such as the promotion of ESCO, low-interest financing, government subsidies and investment in energy-saving technologies and visualization of information about energy consumption and CO_2 emissions. Caveats are that this study was based on a bottom-up analysis, and thus did not take into account the spillover effects of the introduction of mitigation measures, and local-scale technologies or systems such as BEMS and HEMS were not considered due to the lack of data availability and the limitations of global scale modeling.

Acknowledgement

This research was supported by the Global Environment Research Fund A-0808.

References

[1] Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Mitigation of Climate Change, Contribution of Working Group Ⅲ to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK

[2] International Energy Agency (2008) Promoting energy efficiency investments – case studies in the residential sector

[3] International Energy Agency (2009a) Implementing Energy Efficiency Policies

[4] International Energy Agency (2009b) World Energy Outlook 2009

[5] International Energy Agency (2009c) Energy Balances of OECD countries 1960-2007

[6] International Energy Agency (2009d) Energy Balances of Non-OECD countries 1971-2007

[7] International Energy Agency (2010) Energy Prices and Taxes 2010

[8] Hanaoka, T., Akashi, O., Hasegawa, T, Hibino, G., Fijiwara, K., Kanamori, Y., Matsuoka, Y., and Kainuma, M.(2009) Global Emissions and Mitigation of Greenhouse Gases in 2020, Journal of Global Environment Engineering, Vol.14, pp.15-26

[9] The United Nation (2008) World Population Prospects: The 2008 Revision

[10] OECD Development Centre (1998): Construction of an Energy Database for GTAP V4: Concordance with IEA Energy Statistics

[11] U.S. Department of Energy (2003); Model Documentation Report: System for the Analysis of Global Energy Markets (SAGE)

[12] The Energy Conservation Center, Japan; Report on ESCO project in Japan [in Japanese] (1998) URL: http://www.eccj.or.jp/esco/report01/index.html

[13] Institute for Global Environmental Strategies, CDM・JI Project Data, IGES CDMInvestment Analysis Database (as of Nov 2010) URL: http://www.iges.or.jp/en/cdm/report_cdm.html#cdm_a

Strategies for increasing energy efficiency in commercial buildings

ALBU Horaţiu, Ph.D. student[1], GROSULEAC Dan Lucian[2], BEU Dorin, reader[3]
POP Florin, professor[4]

[1, 3, 4] Technical University of Cluj-Napoca, Romania; [2]Philips Romania

Abstract

The paper presents strategies for increasing the electric energy savings in commercial buildings. The strategies take into account the implementation of Best Available Techniques and Sustainable Development in commercial buildings, which focus on two factors: the use of the best state of the art technology available and the environment protection, while the human needs are meet.

The lighting represents an important energy consumer and accounts for a large part of the service cost. Due to the increased regard on environmental and economic issues, energy-saving methods and initiatives are being intensively promoted. Saving of lighting energy requires the use of energy efficient components as well as the application of light control techniques.

The office equipment represents a different energy consumer. Computers, printers, photocopiers, fax machines and scanners have become essential equipment in the modern office buildings. They account for as much as 20% of the office energy consumption. The energy consumption impact regards the electric energy consumption while operating and in sleep mode, the addition to the total electricity demand in the building during peak daytime hours and the generated heat.

Two case-studies are presented that analyse two energy efficiency techniques applicable in commercial buildings. The first case investigates the adequate lighting solution for an existing office building. The second case investigates the financial impact of daily feasible electric energy gains due to the use of power management functions.

Office Energy Consumption and Strategies

Commercial lighting systems consume about 43% of the total electrical energy use by lighting, accounting for 30% of the total energy consumption in commercial buildings. [1] Electronic appliances represent a larger portion of total energy use for residential than for commercial buildings. Personal computers and monitors account for approximately 40% of all energy consumed by office and telecommunications equipment in U.S. commercial buildings. [2] Annual energy use by personal computers is expected to grow 3% per year, while energy use due to other types of office equipment is expected to grow 4.2%. The increasing energy consumption forecast, in spite of energy efficiency improvements, is caused by the continuous penetration of new technologies and greater use of office equipments. [3]

The EU has been the leader in the field of energy efficiency and is taking new measures to promote it. These measures include minimum efficiency requirements for energy using equipment, stronger actions on energy use in buildings, transport and energy generation. The EU has committed to its new energy policy to improve energy efficiency by 20% by 2020. [4]

Energy Saving Methods for Lighting and Office Equipments

Office lighting systems

The light output provided in the commercial buildings in 2005 was due to linear fluorescent lamps (76.5%), incandescent lamps (7.2%), halogen lamps (2.2%), compact fluorescent lamps (7%) and high intensity discharge lamps (7.2%) [1]. Article [5] presents the trend of light sources in Japan in 2009. The compact fluorescent lamp production and sales increased, while the incandescent, general lighting purpose halogen and linear fluorescent lamps had a decreasing trend, compared to the previous year. The increase attention for the LED light sources is also underlined. As Japan represents one of the major exporters of lighting equipment [1] along European Union and China, the trend could be generalized as a global trend.

The factors that have a positive impact on the reduction of lighting energy consumption are [6]: sensible control of lighting; use of daylight; use of presence detectors; intelligent consideration of hours of use; energy-efficient lamps; need-based use of luminaires and lighting solutions, specified for the respective application; constant lighting control (maintenance control).

One aspect of increasing energy savings for lighting energy consumption regards the use of more energy efficient light sources. This can be accomplished with [7]: the use of tri-phosphor fluorescent lamps, the high-frequency operation of fluorescent lamps, the replacement of light sources using old technology with state-of-the-art light sources. The results of the comparison between currently used and new light sources in an office building are presented in [8]. The study shows that if the light sources are undimmed, the LED luminaires and the fluorescent lamps have a close luminous efficacy. As the luminous flux is decreased, the luminous efficacy is maintained approximately at the same value for the LED luminaires dimmed using pulse width modulation techniques, while the luminous efficacy for the fluorescent lamps and the triac dimmed LED luminaire is decreasing. Regarding power quality measurements, the results showed that the use of a triac dimmer generates higher current harmonic amplitudes, with predominant odd harmonic components.

The use of lighting control systems and daylight contribution represents a different aspect that has a positive impact on the reduction of lighting energy consumption. Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Electric energy savings are highlighted for an office building in [9], where different rooms have different light control techniques employed. 40% energy consumption savings are achieved if occupancy and daylight dimming control are used and 22% if occupancy and manual dimming control are employed compared with a room without dimming and occupancy control. Different light control methods used in private office rooms are compared in [10]. The use of an occupancy sensor generates 20-26% of energy savings, while the use of automatic daylight dimming controls creates savings of 21%, compared to manual switching. A different study conducted on open-plan offices shows reduction in electric energy consumption of 35% if occupancy sensors are used alone, 20% for light sensors and 11% individual dimming. Also, if all three controls are used, a reduction of the average daily peak power demand of 65-70% is achieved, compared to a conventional lighting system [11].

The most effective way of reducing the energy consumption in office building lighting is suggested in [12]. The use of dimming in function of daylight availability combined with a central (night) time switch is the most effective way to reduce the energy consumption: an economy of about 50% is possible on a yearly basis for south oriented rooms, compared to an installation where the only light control is the switch-off the lamps outside the office working hours. Also, regulation laying on presence detection has a modest effect for rooms with permanent occupancy (only active during lunch break) but is more effective for rooms of random occupation as conference rooms (up to 20% economy).

Office equipments

The full energy saving potentials for office equipments can be achieved only by reducing the power consumption in every mode (idle, sleep and turned-off) and decreasing the total operating hours. The acquisition of energy efficient office equipment as well as energy efficient use of existing equipment is necessary. Intelligent office equipment with high efficient power management can support the rational use of energy in buildings, but the direct interaction between the user and the office equipment has a great impact to all user specific measures. [13]

An overview of the office equipment operation states (idle, sleep, turned-off) is provided in [3]. The article concludes that power management is most successful among monitors and laser printers, and least successful among desktop computers, inkjet printers, copiers, and fax machines. Turn-off rates are highest (≥ 40%) among integrated computer systems, copiers, scanners, and lowest (≤ 20%) among laser printers and LCD monitors.

Power management is used to automatically reduce the energy used by office equipment that is on but idle, or not in active use. Energy saved by power management in office equipment was estimated in 2001 at 23 TWh/year, with another 17 TWh/year of savings possible if power management were present and functional in all office equipment. Effective use and continued development of power management technology will continue to be an important tool in the overall strategy for reducing energy used by office equipment. [2]

The IEA estimated in 2001 that the energy consumed in the sleep operation state for the office equipments in the residential and commercial sectors combined was accounted for as much as 1% of global CO_2 emissions and 2.2% of OECD electricity consumption, and that significant savings could be achieved by reducing it. [14] Different methods (minimum energy efficiency performance standards, labelling, voluntary agreements, quality marks, incentives, tax rebates and energy-efficient procurement policies) are applied globally to reduce the energy consumed in the sleep operation state in buildings, but most of them capture only a small share of this potential. [15]

Energy Saving Strategies for Commercial Buildings

The reduction of the electrical energy consumption in the commercial sector should consider the application of Best Available Techniques and Sustainable Development strategies. The concept of Best Available Techniques is not aimed at the prescription of any specific technique or technology, but at taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. Special considerations are given towards the consumption and nature of raw materials used in the process and its energy efficiency, the need to prevent or reduce to a minimum the overall impact of the releases to the environment, the technological advances and changes in scientific knowledge or the need to ensure occupational health and safety at workplaces and the risks to it. Guidelines for the interior lighting system design bearing in mind the applicability of the Best Available Techniques and Sustainable Development are presented in [16].

The Sustainable Development Strategy deals in an integrated way with the economic, environmental and social issues and lists the following challenges [17]: climate change and clean energy; sustainable transport; sustainable consumption and production; conservation and management of natural resources; public health; social inclusion, demography and migration; global poverty.

Strategies available for lighting installations and office equipments

The potential for energy savings in the field of lighting can be indicated by rooms or areas with long operating hours, absence of control systems, intermittent occupancy pattern (good conditions for occupancy sensors), low-efficiency lighting technologies which can easily be replaced by more efficient products, no maintenance plan. Daylight within a building has a major effect on the appearance of the space, and can have considerable energy efficiency implications. Building occupants generally prefer a well day-lit space, provided that problems such as glare and overheating are avoided.

Refurbishment of older installations using modern equipment can often result in substantial energy savings in addition to improved visual conditions (elimination of bright reflections from computer screen). Reflectors may be added to the luminaire, retaining the existing light control components. In some cases this can be accompanied by a reduction in the number of lamps to produce the same luminance, with consequential saving (energy savings from 20 up to 50% are estimated to be achievable through improvements in reflectors and shielding).

Improvements in energy efficiency and reductions in costs can be obtained by properly sizing the lighting system and placing the light sources, by introducing lighting controls and by utilising daylight. This can be achieved by a system of localised lighting, where luminaires are related to the work stations. An alternative approach is to install a uniform array of luminaires and then to adjust the light output of each individual luminaire to match the requirements of the area it lights. Additionally, efficient lighting has positive side effects: by reducing electricity consumption for lighting, the thermal load (from lighting) is reduced simultaneously. In buildings with air conditioning, power consumption for cooling will decrease. Improving the lighting quality at the workplace will typically improve the productivity. [18]

Two factors that are important in lowering the energy consumption by office equipment are: users who leave the equipment on during night and equipment with power management features that fail to engage their attributes. In [19] it is showed that about a third of computers and monitors are left on at night, and about two-thirds of printers and copiers are not switched off. The study suggests that users need to be encouraged to turn off equipment at night. Misconceptions refer to the believe that equipments last longer if they are never turned off, and to the behaviour pattern of leaving equipment on.

User perception

The building energy efficiency is related not only to electrical systems and equipment but also to human, climate and architectural variables. With these variables the built space is adapted to the environment where it is located, providing comfort, electrical energy consumption reduction and environment negative impacts reduction. [20]

Despite the fact that various energy saving technologies have been available for some time, their implementation continues to be very slow. Many earlier investigations either took place in laboratory settings, or reported failures in attaining the projected energy savings, revealing significant problems with commissioning and user acceptability.

Several investigations into various open-plan office buildings in the UK showed that occupants generally prefer to have the capability to choose their own lighting environment rather than having to accept lighting levels chosen for them. Questionnaires from 410 occupants collected over a three-year period showed that the occupants viewed the installations that they could control more positively, even when the measured lighting conditions did not meet the recommended lighting levels for offices. The authors noted that individuals purposely used the controls to set their preferred lighting levels. [11] The individual selection of the lighting environment it is not a viable solution for an office building.

Implementing new energy efficient solutions will require clients to be prepared for higher installation costs and users to be open minded to new lighting solutions including their operation. To achieve this will require the attention of the research and development community, particularly those dealing with lighting equipment, light and lighting measurements and lighting design. It will also require investigations by behavioural scientists who specialise in human factors relating to light and lighting. [21]

In most offices, there is no individual responsible for turning off shared equipment, such as printers and copiers at the end of the day. Workers in large offices may be reluctant to turn the equipments off if they are uncertain whether someone else is still working. For these reasons, power management features can be a good method of reducing the electricity use than the ‘turn-off’ programs applicable to personal computers and monitors. [19]

Environmental impact

Substantial reductions in CO_2 emissions from energy use in buildings can be achieved over the coming years using existing, mature technologies for energy efficiency that already exist widely and that have been successfully used. There is also a broad array of widely accessible and cost-effective technologies that can abate greenhouse gas emissions in buildings to a significant extent that has not as yet been widely adopted. Investments in residential and commercial building energy efficiency and renewable energy technologies can yield a wide spectrum of benefits well beyond the value of saved energy and reduced greenhouse gas emissions. Several climate mitigation studies focusing on the buildings sector maintain that, if co-benefits of the various mitigation options are included in the economic analysis, their economic attractiveness may increase considerably – along with their priority levels in the view of decision-makers. Strategic alliances with other policy fields, such as employment, competitiveness, health, environment, social welfare, poverty alleviation and energy security, can provide broader societal support for climate change mitigation goals and may improve the economics of climate mitigation efforts substantially through sharing the costs or enhancing the dividends. In developing countries, residential and commercial-sector energy efficiency and modern technologies to utilize locally available renewable energy forms, can form essential components of sustainable development strategies. [22]

CASE STUDIES – Energy Saving Methods in Office Building

CS1 - Lighting systems in office building

An office building of 6450 m^2, divided in 10 floors was selected for a case study. Each floor is composed of three identical office rooms with a surface equal to 57 m^2, four identical office rooms that have a surface equal to 38 m^2, and two lobbies. The existing lighting installation is composed of luminaires equipped with TL8 2x36 W fluorescent lamps and electromagnetic ballast, for all the rooms in the building. Three lighting solutions are proposed for the replacement of the existing lighting installation: Solution 1 - luminaires equipped with TL5 2x28 W fluorescent lamps and electronic ballast, for all the rooms in the building; Solution 2 – luminaires equipped with TL5 2x28 W fluorescent lamps and electronic ballast for the office rooms, and 37 W LED luminaires (downlights) for the lobbies; Solution 3 - 62 W LED luminaires for the office rooms and 37 W LED luminaires (downlights) for the lobbies.

The technical requirements imposed by the building characteristics consist of: the room surfaces reflection factors were set to 0.20/0.50/0.70, the work-plane was established at 0.80 m for the office rooms and at 0.10 m for the lobbies; the illuminance value at working plane was chosen equal to 500 lx for office rooms, and to 100 lx for lobbies. These requirements are used for calculating the number and position of luminaires needed in the facility, using the DIALux simulation program. The lighting and electrical characteristics of the light sources and the number of luminaires installed for each lighting solution are presented in Table 1. It can be seen that the T5 fluorescent light sources have superior luminous efficacy than the rest of the light sources. The lighting and electrical characteristics of the office building are presented in Table 2. Solution 2, where the T5 luminaires, used together with the LED luminaires, represents the best solution in terms of specific installed power.

Table 1. Lighting characteristics of the lamps

Lighting solution	**Lamp type**	**Lamp**			**Units**
		Power	Luminous flux	Luminous efficacy	
		W	lm	lm/W	
Existing installation	2xTL8-36 W MB	85	5700	67.06	620
Solution 1	2xTL5-28 W HF	62	5200	83.87	640
Solution 2	2xTL5-28 W HF	62	5200	83.87	510
	37 W LED	37	2000	54.05	180
Solution 3	62 W LED	62	3750	60.48	720
	37 W LED	37	2000	54.05	180

Table 2. Lighting characteristics of the office building

Lighting solution	**Office building**		
	Luminous flux	Power	Specific installed power
	lm	W	W/m^2
Existing installation	4,154,000	52,700	10.52
Solution 1	3,328,000	39,680	7.92
Solution 2	3,012,000	38,280	7.64
Solution 3	3,060,000	51,300	10.24

The iluminance levels at work-plane for the large office room are shown in Table 3.

Table 3. DIALux simulation iluminance levels at work-plane level

Lamp type	**E_{av}, lx**	**E_{max}, lx**	**E_{min}, lx**	**E_{min}/E_{av}**
2xTL8-36 W MB	503	734	256	0.508
2xTL5-28 W HF	509	825	261	0.513
62 W LED	501	624	295	0.588

Next, a financial analysis is done taking into consideration the reporting period of 20 years, the inflation equal to 3%, and the energy costs equal to 0.08 Euro/kWh. The initial cost, the operational costs, the energy costs for the entire period and the return of investment for all the lighting solutions are presented in Table 4. The course of overall costs of solution over lifetime can be seen in Figure 1.

Table 4. Total costs for the lighting solutions, Euro

Lighting solution	**Initial cost**	**Operational cost**	**Energy costs**	**Return of investment**
Existing installation	105,503	403,370	298,610	-
Solution 1	175,466	311,711	217,937	1.31
Solution 2	241,075	308,137	214,577	0.70
Solution 3	1,184,250	396,256	303,256	0.01

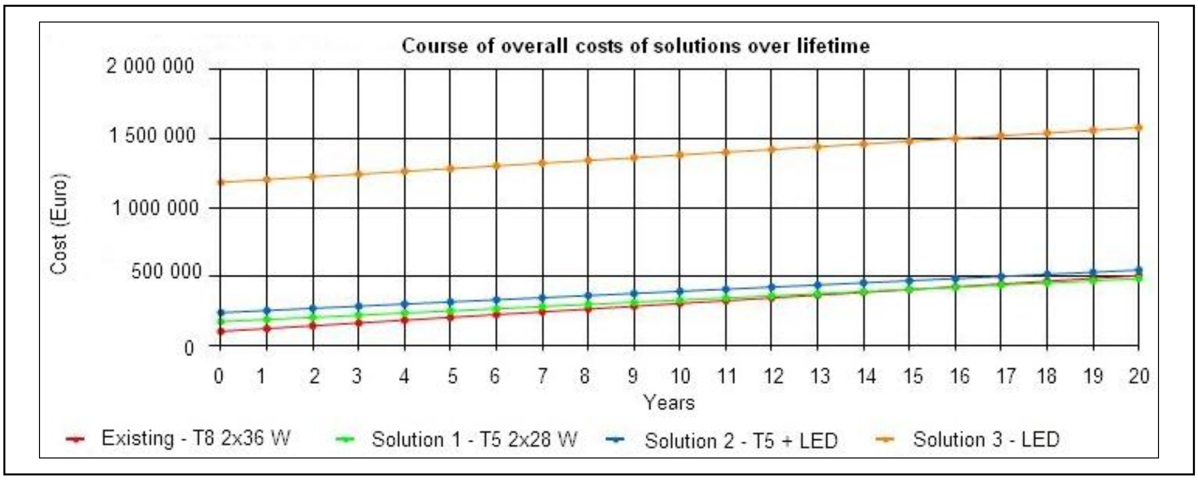


Figure 1. The cumulative costs throughout the reporting period

The information presented in Table 1 and Table 2 indicates that Solution 3 is the adequate solution to be used for the replacement of the existing installation, due to the lower power consumption. However, the financial analysis from Table 4 and Figure 1 shows that, due to the smaller initial cost, the Solution 2 is the best solution to replace the existing installation. Table 3 supports this statement, as the selected solution provides an illuminance level at the work plane within the recommended value.

CS2 - Office equipment in office building

The financial impact of daily feasible electric energy gains due to the use of energy-saving methods was investigated for the same office building. The following assumptions were taking into account:

- Each office room with a surface equal to 38 m^2 has a 6 m^2/person working space. The chosen value is within the minimum requirement intervals that allow different office applications to be run. [23]
- Each office room with a surface equal to 57 m^2 has a 5 m^2/person working space. The person working space is within the minimum requirement interval for a basic workstation. [23]
- The office working hours were chosen from 8:00 to 17:00, with lunch break hours in the interval 11:00 ÷ 13:00 (one hour/person). It was considered also a 20 minutes break at each two hour period.
- Each person was assumed to have access to office equipment. Each office worker was assumed to have access to computer systems. From the total number, 30% have access to computer systems composed of desktop computers, monitors and inkjet printers, 45% to computer systems composed of desktop computers and monitors and 25% to laptops.
- The period until the desktop computer, monitor and printer enter in sleep mode was assumed at 10 minutes; the period until the laptop enters in sleep mode was assumed at 5 minutes.

The power consumption for each computer systems was determined by measurements at MicroDERLab Laboratory, Polytechnic University of Bucharest, with the use of a Fluke 43 measurement equipment [24]. The equipment characteristics are presented in Table 6. The measurements were taken during four different “power states”: off, sleep, idle and active. The results are presented in Table 7.

The equipments comply with the off and sleep operation mode requirements of Energy Star Standards (≤ 2 W for off mode, and ≤ 4 W for sleep). [25] The measured equipment does not comply with the requirements of Directive 2005/32/EC, due to its production date. [5] The 24 hour diversity profile for typical occupancy loads in office environments is presented in Figure 2. [26]

Table 6. Measured office equipment characteristics

Equipment	Characteristics
Desktop	CPU: Intel Pentium 4 2.8 GHz, RAM: 512 MB, Hard Drive: 80GB 7200 rpm, Video Card: NVIDIA GeForce 6200
Laptop	CPU: 1.6 GHz Pentium M 715, RAM: 512 MB, Hard Drive: 80 GB 4200 rpm, Video Card: NVIDIA GeForce FX GO 5200, Monitor: 15.4'' WXGA screen
Monitor	Horizon 17'' LCD, Model: 7005L
Printer	HP deskjet, Model: 5150

Table 7. Energy consumption for computer systems functioning at different power states

Computer system	Operation state			
	Off	Sleep	Idle	Active
	W	W	W	W
Desktop+Monitor	3.79	5.17	83.05	129.17
Desktop+Monitor+Printer	7.41	8.79	87.88	134.00
Laptop	0.85	1.60	44.15	64.84

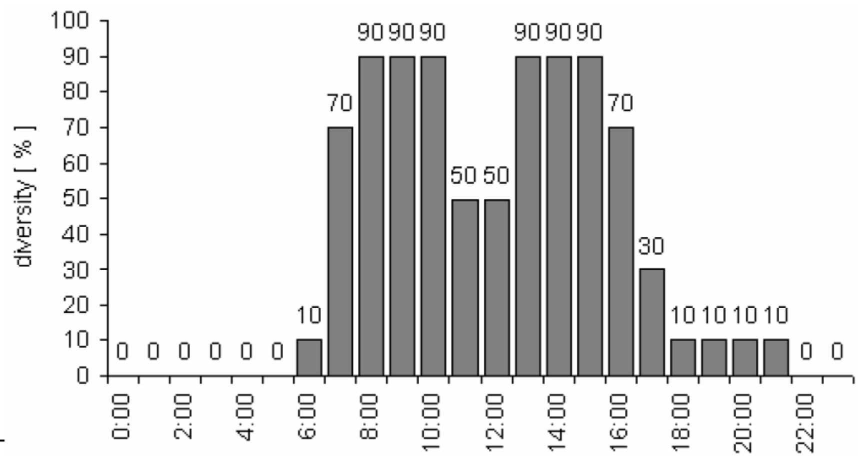


Figure 2. The 24-hour diversity profile for typical occupancy loads in office environments [26]

Taking all the previous assumptions into considerations, for the existent office building of 6450 m^2, a number of 570 working persons have been presumed. For establishing the different energy consumption during one working day in the office building, five scenarios have been considered:

- Scenario 1: idle + active operation during the working hours for all equipments, idle operation for one third of computer systems in rest of the time, while the remaining percent is in sleep mode operation (worst case scenario);
- Scenario 2: idle + active operation during the working hours and sleep operation rest of the time;
- Scenario 3: idle + active operation during the working hours and off operation rest of the time;
- Scenario 4: idle + active operation during the working hours, sleep operation during lunch and break times and off operation rest of the time;
- Scenario 5: idle + active operation during the working hours, sleep operation during lunch and break times and disconnected from the power network rest of the time (best case scenario).

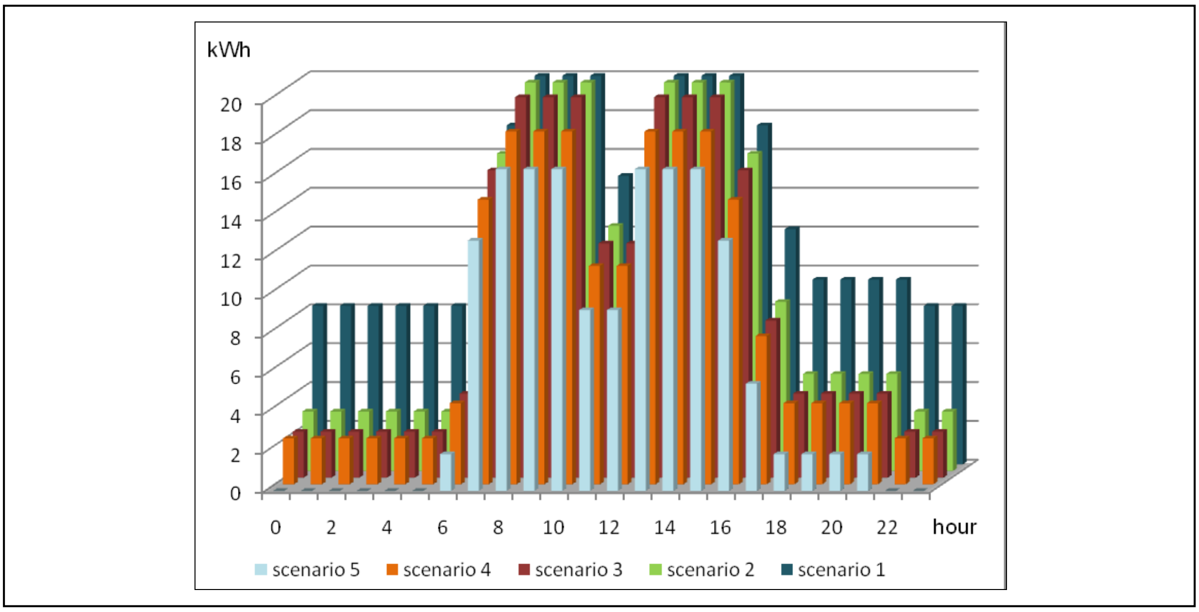


Figure 3. The 24-hour energy consumption for all five scenarios

Table 8 shows the daily and monthly energy savings that can be achieved by employing different power manager features. The energy cost has been selected to be equal to 0.08 Euro/kWh. It has been showed that potential savings up to 49% can be achieved in the office equipment consumption with power management functions and responsible user behaviours.

Table 8. Daily and monthly potential energy savings for all five scenarios

Scenarios	Daily energy consumption		Monthly energy consumption		Monthly savings
	kWh	Euro	kWh	Euro	%
Scenario 1	310.722	24.85	6835.891	546.87	-
Scenario 2	236.435	18.92	5201.583	416.13	23.91
Scenario 3	221.902	17.75	4881.857	390.55	28.59
Scenario 4	208.136	16.65	4579.004	366.32	33.02
Scenario 5	158.737	12.70	3492.230	279.38	48.91

Conclusions

The paper analyses the problem of energy efficiency in office buildings, focusing on lighting systems and office equipments. Literature study conclusions are presented to emphasize the availability and successfulness of the existing energy efficiency techniques. Since their performance is close related to other variables to, the user perception towards the use of energy saving methods is discussed.

The presented case-studies show the importance of energy efficiency techniques. In the first case study, the feasibility of re-lamping the lighting system from an office building is analysed. From the proposed lighting solutions, the Solution 2 (luminaires equipped with T5 fluorescent lamps and electronic ballasts) is the most adequate to replace the existing one. Besides the energy economy and user satisfaction, the luminaires equipped with T5 fluorescent lamps and electronic ballast present the opportunity of employing different light controls, and therefore, the possibility of increasing the energy savings. The second case compares different scenarios involving the use of power management function of office equipments. The study is based on electric energy consumption measurements done on different types of office equipments that are still used in office buildings. Calculating the monthly energy consumption, it is showed that savings up to 49% can be achieved by power management functions and responsible user behaviours.

References

[1] International Energy Agency. *Light's Labour's Lost – Policies for Energy-efficient Lighting*, OECD/IEA, 2006.

[2] Judy A. Roberson et. al. *Energy Use and Power Levels in New Monitors and Personal Computers*, July 2002. LBNL-48581. Can be downloaded from: http://enduse.lbl.gov/info/lbnl-48581.pdf.

[3] Judy A. Roberson et. al. *After-hours Power Status of Office Equipment and Inventory of Miscellaneous Plug-Load Equipment,* January 2004. LBNL-53729. Can be downloaded from: www.osti.gov/bridge/servlets/purl/821675-waYRd0/native.

[4] http://ec.europa.eu/energy/energy_policy/doc/01_energy_policy_for_europe_en.pdf.

[5] Yasuda T. et al., *Light Sources and Lighting Circuits*, Journal of Light and Visual Environment, Vol. 33, No. 3. 2009.

[6] http://www.zumtobel.co.uk/download/ilr_cp_TheLightingHandbook.pdf.

[7] Van Tichelen P. et al. *Project Report Lot 8: Office lighting*, Study for the European Commission DGTREN unit D3, 2007.

[8] Albu H., Halonen Liisa, Tetri E. and Pop F. *Office lighting with currently used and new light sources* – Journal Ingineria Iluminatului – Lighting Engineering, Volume 12, Number 2, December 2010, pp. 5 – 22. ISSN 2968-9853 online. Can be downloaded from: journal.florinrpop.ro/2010-2/Revista%202_2010.pdf.

[9] Bhusal P., Tetri E. and Halonen Liisa. *Quality and efficiency of office lighting*, Proceedings of the 4th European Conference on Energy Performance and Indoor Climate in Building and the 27th International Conference AIVC (Lyon, France, 2006).

[10] Jennings Judith D., Rubinstein F. M. and Di Bartolomeo D.. *Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed,* IESNA Annual Conference (New Orleans, August 1999).

[11] Galasiu A.D., Newsham G.R., Suvagau C. and Sander D.M. Energy saving lighting control systems for open-plan offices: a field study, 2007. Can be downloaded from: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc49498/nrcc49498.pdf.

[12] Roisin B., Deneyer A., D'Herdt P., Diga Silvia-Maria and Eugene C. *Optimization of lighting power consumption in offices*, International Lighting Symposium "Modern Quality Solutions for an Efficient Lighting" (Sinaia, Romania, October 12-14, 2006).

[13] http://www.eu-greenbuilding.org/fileadmin/Greenbuilding/gb_redaktion/modules/GreenBuilding_ Office_Equipment_Module_V2.pdf.

[14] International Energy Agency. *Things that go blip in the night. Standby power and how to limit it* OECD/IEA, 2001.

[15] Levine M., Ürge-Vorsatz Diana et. al. *Residential and commercial buildings. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. ISBN-13 978-0-511-36651-2.

[16] Albu H., Grosuleac D. and Pop F. *Interior lighting design based on Best Available Techniques and Sustainable Development*. Simpozionul Internaţional de Eficienţă Energetică, SIEE 2010, pp. 72 – 83 (Cluj – Napoca, Romania October 7-10, 2010). ISBN 978-973-133-822-4.

[17] http://ec.europa.eu/sustainable/welcome/index_en.htm.

[18] http://re.jrc.ec.europa.eu/energyefficiency/greenbuilding/pdf%20greenbuilding/GreenBuilding_ Lighting_Module_V3.pdf.

[19] Picklum R. E., Nordman B., Kresch Barbara. *Guide to Reducing Energy Use in Office Equipment*, March 20, 1999. Can be downloaded from: http://eetd.lbl.gov/bea/sf/guider.pdf.

[20] Batista N.N. and Rovere E. L. *Energy Building Performance and Energy Efficency Level Evaluation*. RIO 9 - World Climate & Energy Event (Rio de Janeiro, Brazil, March 17-19, 2009).

[21] Loe DL. *Energy efficiency in lighting - considerations and possibilities*, Lighting Res. Technol. pp: 209–218, 2009.

[22] European Commission, *Green paper on energy efficiency. Doing more with less.* 2005. Can be downloaded from: http://ec.europa.eu/energy/efficiency/doc/2005_06_green_paper_book_en.pdf

[23] http://www.ccohs.ca/oshanswers/ergonomics/office/working_space.html.

[24] Albu H. and Pop F. Research Report PRODOC UTC-N. Report on the research traineeship at Polytechnic University of Bucharest, Romania, between November 29 – December 10, 2010.

[25] http://www.energystar.gov/index.cfm?c=computers.pr_crit_computers.

[26] Bourgeois D., Detailed occupancy prediction, occupancy-sensing control and advanced behavioural modelling within whole-building energy simulation, Doctoral Thesis, Faculté Des Études Supérieures Université Laval (Québec, Juin, 2005).

The presented study is co-financed by the European Social Fund - FSE - through the development Project of doctoral studies in advanced technologies – “PRODOC” POSDRU/6/1.5/S/5 ID 7676, Technical University of Cluj-Napoca, Romania.

Looking behind the curtains – a comprehensive snapshot of the appliances and lighting stock in Australian homes

Jack Brown and Lloyd Harrington, Melanie Slade

Energy Efficient Strategies, Department of Climate Change and Energy Efficiency, Australia

Keywords

Lighting stock, appliance stock, technology changes.

Abstract

The ownership of appliances and equipment in homes is regularly surveyed by the Australian Bureau of Statistics. Good data on major appliances, fuel sources, major end uses and demographics is recorded every three years and then publicly released. But there are many small end uses which are not recorded during these types of surveys.

As part of a strategy to monitor and evaluate standby power trends, Australia has undertaken three intrusive surveys of households. These studies catalogue and record every product in every home surveyed. Low power modes of over 20,000 appliances have been recorded in the years 2000, 2005 and 2010. While these studies cover a relatively small number of homes (64 in 2000, 120 in 2005, 150 in 2010), they provide deep insights into the key attributes of appliances.

For the first time, the 2010 study comprehensively audited home lighting stock. Data on room size and use, together with lamp input power and technology attributes were recorded, providing a basis for a preliminary assessment of the energy efficiency potential of improved lighting technologies.

Appliance numbers in homes are growing, as is the associated standby energy consumption. Network capable product numbers are also growing quickly. Australia is in the midst of a conversion from top loading to front loading washing machines, and single function printers to multifunction devices. The CRT to LCD television transformation is more dramatic, as are the increase in screen sizes.

Lighting trends are more disturbing. While the humble incandescent bulb has been largely banned through regulatory measures, many Australians have a love affair with low voltage quartz halogen downlights, which are hardly better in efficiency terms. Significantly, this survey provides the first sound basis for estimating the efficiency potential of residential lighting. But the large diversity of existing technologies and fittings in the stock, and the range of user attitudes makes the achievement of this potential less than straight forward.

Introduction

This paper provides a discussion on the current understanding of the stock of installed appliances and lighting in Australian households. It looks into the levels of data that are available concerning both appliances and lighting, and discusses in greater depth the 2010 appliance and lighting survey.

While there is a good level of publicly released data available from the Australian Bureau of Statistics (ABS) concerning major appliances, fuel sources, major end uses and demographics, there are many small end uses that are relatively uninvestigated. These small end uses are of interest to policy makers, as although their individual unit energy consumption is comparatively small, they may have high penetration and ownership[1]. The level of data and understanding concerning installed lighting stock in Australian homes is minimal at best.

Good data for both appliances and lighting is vital when creating energy efficiency policy, as assumptions concerning program impact, cost and response can then be calculated with greater certainty. This is especially important in the writing of Regulatory Impact Statements (proposals to regulate), which include a benefit cost analysis of the impacts on the product marketplace, and need to investigate all the economic, social and environmental aspects of a regulatory proposal.

Existing Data

The existing data for Australian residential lighting and appliances stock is varied. Several key publications and studies document the stock of appliances, and provide a good understanding of the installed base. The available dataset for lighting isn't as extensive, and work is being undertaken to expand it.

ABS 4602 and Previous Intrusive Surveys

The Australian Bureau of Statistics (ABS) regularly surveys different aspects of home energy and appliance use and ownership. The key publication concerning this is ABS 4062 – Environmental Issues: Energy Use and Conservation. ABS 4602 has been released about every three years since 1994[2], and provides key data and information on:

- Dwelling structure and characteristics;
- Energy sources and dwellings;
- Heaters and coolers; and
- Household appliances.

New items are periodically included as technology change is seen to occur, allowing the report to follow the trends and drivers in household energy use [1]. While this data is essential for allowing policy makers to understand the key driving forces in residential energy use, it does not document many smaller end uses.

Since 2000, the Australian Government has been investigating the low power mode attributes of appliances found in homes. These investigations have come in the form of intrusive (residential) surveys, undertaken every five years. While they primarily focus on appliance low power modes (standby), they also provide a good understanding of the ownership trends of different appliance types, as well as some age and use characteristics.

The first survey was undertaken in 2000 and consisted of a sample of 64 homes, with some 2,300 individual appliances measured [2]. In many ways, this study provided a base for appliance ownership in homes. It complemented the data found in ABS 4602, and filled in some of the knowledge gaps concerning small end use appliance ownership and characteristics.

A second survey was undertaken in 2005 with a sample of 120 homes. This doubling of the sample size compared to the 2000 study was intended to increase the representativeness of the survey and

[1] Ownership – the ratio of stock to the total number of households. This value is usually given as a decimal number and can exceed 1.0

Penetration – the proportion of households in which one or more of a particular appliances type is present (irrespective of the number of units of that appliance in a household). This value is usually given as a percentage and the maximum value is 100%

[2] Some additional ABS surveys of energy and ownership were undertaken in the 1980's.

results. The 2005 survey included almost 8,000 individual appliance measurements, and documented key appliance age and usage trends [3].

The main changes found concerning appliances in 2005 compared to 2000 were:

- Increasing appliance ownership, especially for products with low power modes and external power supplies;
- Increasing prevalence of 'smart' appliances, with functions like fuzzy logic and favourite settings savers;
- Increasing computer ownership, and subsequent increase in computer peripheral ownership;
- Increasing home entertainment appliance ownership, including more complex and higher power DVD recorders, set top boxes and home theatre components [3].

Current Lighting Data

To date, not a great deal is know about Australia's lighting energy consumption. It is estimated that lighting consumes between 8% and 15% of the average household electricity budget, although this differs depending on the makeup of the installed lighting technologies and user behaviour [4]. ABS 4602 does contain some information concerning lighting, but only to the extent of quantifying the use of fluorescent lighting [1], with even this data not having a high level of detail. In 2007, Australia announced a phase out of incandescent bulbs, with the intention of increasing the general efficiency of the installed lighting stock, and along with this, minimum energy performance standards (MEPS) have been introduced for:

- Ballasts for linear fluorescent lamps;
- Linear fluorescent lamps;
- Compact fluorescent lamps;
- Transformers and electronic step-down convertors for ELV lamps; and
- Incandescent lamps.

Compact fluorescent lamps (CFL) are expected to increase in penetration as the installed stock of incandescent lamps decreases. This is expected to drive lighting energy consumption downwards in the short term. But in spite of technology and MEPS introductions, lighting energy consumption is still projected to increase over the coming years. This is primarily driven by increasing installation of quartz halogen (QV) lighting and increasing household numbers [4].

Policy makers would like to better understand not only the installed residential lighting stock, but also householder attitudes and user behaviour, to allow program improvements and enable better targeting of resources.

2010 Appliance and Lighting Survey

The 2010 appliance and lighting survey was completed using a sample of 150 homes. This is an increase from the previous 2005 and 2000 appliance studies of 120 and 64 houses respectively. The houses were located in the major cities of Australia's eastern seaboard (Brisbane, Melbourne and Sydney), and also included some houses from regional Victoria to account for any non-metropolitan influences. The sample was balanced as closely as possible against key demographics identified in the 2006 Census, to allow dataset extrapolation across all of Australia. However, as with any survey with a small sample size, it includes some possible skews.

For appliances, there are several reasons why the survey is being undertaken:

- To quantify the low power mode (standby) attributes of the average house;
- To establish and investigate any changes in appliance technologies;
- To qualify the ownership and penetration of all appliance types;
- To investigate the ownership and penetration of new appliance types and technologies; and
- To quantify general usage and age trends for key appliance types.

These reasons are similar in nature to past appliance surveys, with the 2010 survey adding to past knowledge and documenting changes that are found in the stock.

As has been stated, the understanding of the makeup and attributes of the lighting stock in Australian homes is seriously incomplete and not well understood. The 2010 survey will greatly add to this understanding and make an extremely valuable contribution to the current dataset.

Key Appliance Findings

A total of just over 10,000 appliances were measured for the 2010 appliance survey, compared to 8,000 in 2005 and 2,300 in 2000 (although the number of households in those surveys were correspondingly smaller). As for the 2005 survey, around 300 different appliance types were found. These range from kettles and smoke alarms to ducted air conditioners and televisions, as anything that is connected to mains energy is documented as part of the survey. Table 1 outlines the key findings for the latest intrusive appliance survey. Generally, the average number of appliances found per house has increased over time, the average low power mode consumption per house has increased, but there are also increasing numbers of appliances that are unplugged when not in use. Thus, average low power mode consumption has increased, although it is expected that new regulations introduced concerning standby power have also had an impact at a product level, along with changing consumer attitudes and behaviour due to increasing electricity prices.

Table 1 - Intrusive Surveys: Key Appliance Findings

Survey Item	2010 Survey Finding
Average number of appliances per house	67
Average low power mode consumption per house	94.5W
Average number of appliances using energy	26.5
Average number of appliances not using energy (power = 0, or unplugged)	40.2
Average power of appliances using some standby energy	3.6W
% of appliances found ‘unplugged’	37%
Average total electricity (standby) used per year	830 kWh/y

[5]

Network Products

There is an increasing prevalence of products in the home that either are network connected or network capable. Network products are generally designed for fast and effective network function, with little to no thought concerning energy consumption [6]. This attribute, coupled with rapidly increasing ownership, has flagged these products as a priority concern for policy makers. The main appliance types that have network capability are found in the home office and home entertainment groups. This is a substantial change from previous surveys where network capable products were only identified in the home office group, primarily in laptop and desktop computers, and the corresponding modem products that provided internet connection. The range and ownership of these networking devices is shown in Table 2 and 3.

Table 2 – Networking Products: 2010 Intrusive Survey – Connection Facilitation Devices

Product	Ownership	Average Age (Yrs)*
Hub	0.07	NA
Modem - ADSL	0.33	4.6
Modem – ADSL Wireless	0.39	4.6
Modem - Cable	0.17	4.2
Router	0.04	7.0
Router - Wireless	0.29	3.2
Switch	0.11	4.4
VOIP Equipment	0.17	1.7

* Using 2010 as the base year. [5]

Table 3 – Networking Products: 2010 Intrusive Survey – Connection Capable Devices

Product	Owner -ship	Average Age (Yrs*)	Connection Capable	Connected – Mobile	Connected - Wired	Connected – Wireless	Not Connected
Computers - Desktop	0.97	5.0	83.0%	2.0%	64.0%	31.0%	3.0%
Computers - Integrated	0.07	4.4	80.0%	0.0%	62.0%	38.0%	0.0%
Computers - Laptop	1.37	3.8	94.0%	7.0%	12.0%	79.0%	1.0%
Games Consoles	0.81	5.2	56.0%	1.5%	20.5%	23.5%	54.5%
Media Hub	0.13	NA	10.5%	0.0%	0.0%	66.5%	33.5%
Televisions - LCD	0.78	2.6	8.5%	0.0%	20.0%	0.0%	80.0%
Televisions – LED (LCD)	0.07	1.0	80.0%	0.0%	50.0%	25.0%	25.0%
Televisions – Plasma	0.21	3.5	6.5%	0.0%	100.0%	0.0%	0.0%

* Using 2010 as the base year. [5]

Appliance Technology Changes

There are also a number of interesting technology changes that are currently underway in Australian homes, with the key changes outlined in Table 3. The speed of the change in ownership from CRT to LCD televisions is quite astounding, especially as only five years ago, the ownership of LCD televisions was close to zero. With this change, comes an increase in average screen size and a corresponding increase in on mode energy consumption. It is interesting to note that the ownership of plasma televisions has stayed fairly stable over the last five years.

Like televisions, there is a technology change occurring for clothes washers, as the dominate type moves from a top loading to a front loading configuration. This process has accelerated over the last five years, to the point where the ownership of both types are almost equal. Another interesting technology change that has occurred over the last five years concerns printers and multifunction devices. Multifunction devices normally include printer, scanner and copier functions, and may rarely include a fax function as well. They have replaced scanners (predominately USB powered) in homes, and are steadily eating into the ownership of both inkjet and laser printers.

Table 3 – Appliance Technology Changes: 2010 Intrusive Survey

Product	2010 Ownership	2010 Age (Yrs)*	2005 Ownership	2005 Age (Yrs)**
Televisions – LCD[3]	0.78	2.6	0.00	N/A
Televisions – LED (LCD)	0.07	1.0	0.00	N/A
Televisions – CRT	1.05	11.2	2.07	7.7
Televisions – Plasma	0.21	3.5	0.04	1.8
Clothes Washers – Front	0.53	5.0	0.26	3.8
Clothes Washers – Top	0.47	9.2	0.73	8.1
Printers – Inkjet	0.18	6.9	0.89	4.4
Printers – Laser	0.25	4.8	0.13	3.6
Multifunction Devices	0.68	3.6	0.23	2.3

* Using 2010 as the base year. ** Using 2005 as the base year. [3] & [5]

Key Lighting Findings

Around 7,000 lamps were documented in the 2010 lighting survey, with houses found to have an average lamp count of 50.0 and average lamp Wattage of 52.3W. Lighting is a complex issue, with householder habits, attitudes and installed fitting configuration having a massive impact on the potential to reduce lighting energy consumption. Lighting in a home is used for many reasons and purposes, and the requirements and lighting desires vary from user to user. The general knowledge and understanding concerning lighting technologies and choices also varies greatly, with this complicating any attempt to increase the efficiency of installed lighting stock. This survey fills a hole in the understanding and data concerning lighting, and provides the first sound basis for estimating efficiency potential of residential lighting. Unfortunately, the raft of existing technologies and fittings in the stock, and user attitudes makes the achievement of this potential less than straight forward.

Table 4 outlines the key lighting technology attributes found in the survey. Although many forms of incandescent lamps have been phased out, the installed ownership of this technology is still quite high (over a quarter of lamps in an average house). It is both encouraging to see that the ownership of compact fluorescent lamps is high, although it is concerning to see that low voltage quartz halogen lamps also have a very high ownership. Low voltage halogen lighting are installed as flush mounted downlights and has become a popular technology for installation within new homes. This form of lighting has numerous downsides including poor efficiency, potential fire risks and impact on the effectiveness of ceiling insulation. Worryingly, the level of householder knowledge concerning these issues seems to be poor.

Table 4 – Key Lighting Technology Attributes: 2010 Intrusive Survey

Average per House Dominate Fitting*	Incandescent	Halogen	CFL*	LFL**	LED	Unknown	Missing
Number of Lamps	12.69	16.11	14.39	4.23	0.67	1.11	0.77
Number Share	25.4%	32.2%	28.8%	8.5%	1.3%	2.2%	1.5%
Watts Total	1336	878	196	141	3	60	0
Watts Share	51.1%	33.6%	7.5%	5.4%	0.1%	2.3%	0.0%
Watts/Lamp	105.3	54.5	13.6	33.3	5.1	54.0	0.0
Lumens Total	16165	13629	10742	12743	179	730	0

[3] Average screen size has increased over 20cm in the last five years.

Lumens Share	29.8%	25.2%	19.8%	23.5%	0.3%	1.3%	0.0%

* Compact Fluorescent ** Linear Fluorescent. Missing is where lamp is blown or removed. [5]

The potential for analysis that can be undertaken on this survey data is vast, with one interesting investigation concerning lighting attributes and characteristics by room type. Table 5 outlines these findings. It can be seen that the living areas (kitchen/lounge/dining) are the most interesting space for lighting, as they have the highest share of floor area, along with the highest number of fixed lamps.

Table 5 – Room Lighting Attributes: 2010 Intrusive Survey

Average per zone	Living	Sleeping	Other-Indoor	Outdoor	Whole House
Number of Rooms	2.7	3.4	6.0	3.0	15.1
Floor Area (m^2)	60	45	34	18	157.6
Share Floor Area	38.3%	28.4%	21.7%	11.7%	100.0%
Power Density W/m^2	10.1	8.2	29.7	NA	
Lighting Levels (all) L/m^2	233	183	513	NA	
Fixed Lamps	14.3	6.8	12.5	9.2	42.9
Plug Lamps	2.0	4.3	0.4	0.5	7.1

Notes: Some outdoor spaces had a nominal floor area, but mostly this is not applicable.

The question of retrofitting lighting to increase general efficiency is a difficult one, and not as straight forward as a swap of an incandescent lamp with a compact fluorescent lamp. There is no doubt that some houses have the potential to lower their electricity bills through the installation of a greater percentage of compact fluorescent lighting, but on the whole, incandescent lamps are found in areas of the house with lower use characteristics. Retrofitting low voltage halogen lighting is a difficult task, as currently there are limited options available to householders without requiring a renovation of the room's ceiling (due to holes in the plaster). LED lighting has the potential to fill this void, but currently seems to be too expensive, with possible issues with colour rendering, lifetime (reliability) and lamp range.

Conclusions

The 2010 intrusive survey has added a great deal to the understanding and datasets for both appliances and lighting in Australia. For appliances, it continues to document the trends, ownership and characteristics of all appliances found in homes, but especially for small end uses, which other data sources lack detail. It has established the ownership of networking products, including the level of connection in these products, important considering the rapid growth in this area. Finally for appliances, it follows the change in technology that has occurred since the last survey 5 years ago, and documents this clearly for clothes washers, televisions and printing devices.

For lighting, the 2010 intrusive survey is extremely important. It documents in Australia for the first time a comprehensive picture of technologies, fittings, room types and floor areas, Wattages, and ownership, and allows analysis of this data for any range of scenarios. It helps to create a picture of what types of lighting householders like to install in different rooms, as well as the Wattage of light that they like to use. Possible retrofitting of lighting to increase general efficiency levels is not a straight forward task, in part due to householder attitudes and knowledge levels. The survey has shown that although lighting is a complex issue, this data goes a long way to build on currently levels of understanding and will help policy makers when making decisions in the future.

References

[1] ABS. *Environmental Issues – Energy Use and Conservation*. Available from http://www.abs.gov.au/ausstats/abs@.nsf/PrimaryMainFeatures/4602.0.55.001. 2008.

[2] EES & Energy Consult. *Quantification of Residential Standby Power Consumption in Australia: Results of Recent Survey Work*. Available from http://www.energyrating.gov.au/library/detailsstandby-2001.html. 2001.

[3] EES. *2005 Intrusive Residential Standby Survey Report*. Available from http://www.energyrating.gov.au/library/details200602-intrusive-survey.html. 2006.

[4] DEWHA. *Energy Use in the Australian Residential Sector – 1986 to 2020*. Available from http://www.energyrating.gov.au/library/details2008-energy-use-aust-res-sector.html. 2008

[5] EES. *2010 Appliance and Lighting Survey Data*. Currently unreleased, will be available from http://www.energyrating.gov.au/ in the electronic library some time in early 2011. 2011.

[6] EES. *Standby Power and Low Energy Networks – issues and directions*. Available from http://standby.iea-4e.org/news/standby-power-and-low-energy-networks-report-released-. 2010.

Understanding residential energy consumption and efficiency trends in the European Union

Bettina Hirl, Paolo Bertoldi
European Commission, JRC

Abstract

In 2005 in-depth survey of the electricity end-use consumption and energy efficiency trends was started in order to assess the energy efficiency potential in the building sector in the European Union Member States (EU-27)[1]. The survey is updated every two years, the last one being carried out in 2011.

The survey aims to link the efficiency improvements to the trends in energy consumption. Efficiency trends monitored include the monitoring of sales of labelled appliances, sales of energy efficient lamps and sales of consumer electronics. By comparing energy consumption with other trends (e.g. energy prices, GDP, people in households) we get an estimate of the impact of energy efficiency policies (e.g. labelling, efficiency standards etc.).

Accounting for electricity and gas consumption is a very important step for the development of energy policies, but so far these consumption analyses have been neglected or underestimated in policy development and related research. This paper gives an overview of the most important figures and results of the updated in-depth survey.

1. End-use energy consumption trends and EU energy efficiency policies

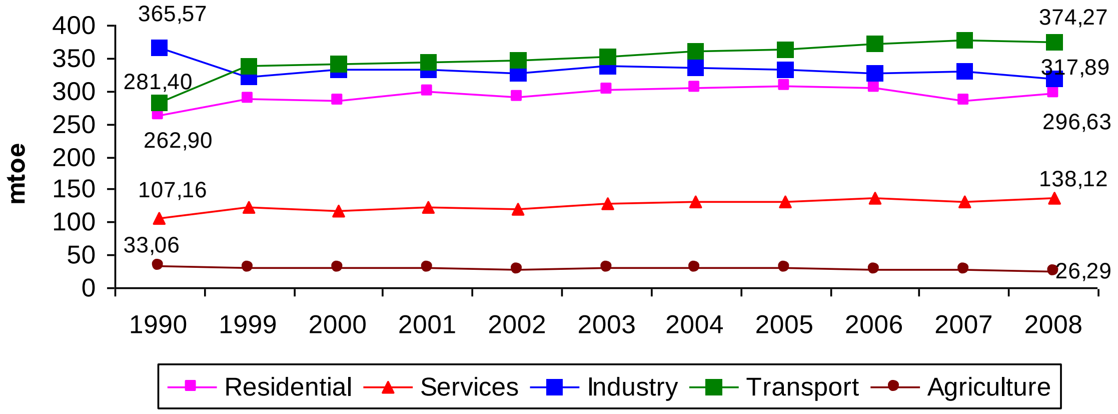
During the last two decades the final energy consumption in the EU-27 grew by more than 9% (between 1990 and 2008 the growth rate was 9.45%) but dropped down by -1.06% between 2004 and 2008. In the residential sector the decrease is even more profound: -2.88% in the 2004/2008 timeframe. In the agricultural and industry sectors growth rates are also negative during this period: -5.58% and -15.55% respectively. Only in the service and transport sector final energy consumption was on the rise: It grew by 5.61% and 3.35% respectively. Energy consumption in the 12 new member states is growing by 2.45% between 2004 and 2008 whereas in the EU-15 area consumption fell by 1.65% during the same period. Looking at the individual sectors, energy consumption in the NMS-12 decreased between 2004 and 2008 for the residential, the industry and the agricultural sector (-1.22%, -6.54% and -13.14% respectively). The residential sector in the EU.27, EU-15 and NMS-12 I son third place for energy savings during this four year period after the agricultural and the industry sector.

Table 1 EU-27 Final energy consumption (source Eurostat, JRC)

			Final	Residential	Services	Industry	Transport	Agriculture
EU-27	1990	(ktoe)	1.067.691	262.903	107.161	365.566	281.399	33.059
	1999	(ktoe)	1.113.377	287.726	122.048	322.250	338.971	29.805
	2000	(ktoe)	1.117.232	285.418	116.503	332.420	341.003	29.897
	2001	(ktoe)	1.142.972	299.038	124.272	333.434	344.196	29.611
	2002	(ktoe)	1.128.875	291.622	120.665	328.238	347.636	28.938
	2003	(ktoe)	1.165.853	302.724	128.103	337.134	352.457	30.438

[1] The European Union comprises the following 27 countries: Austria (At), Belgium (Be), Bulgaria (Bg), Cyprus (Cy), Czech Republic (Cz), Denmark (Dk), Estonia (Ee), Finland (Fi), France (Fr), Germany (De), Greece (Gr), Hungary (Hu), Ireland (Ie), Italy (It), Latvia (Lv), Lithuania (Lt), Luxembourg (Lu), Malta (Mt), Netherlands (Nl), Poland (Pl), Portugal (Pt), Romania (Ro), Slovak Republic (Sk), Slovenia (Sl), Spain (Es), Sweden (Se), and United Kingdom (UK).

	2004	(ktoe)	1.181.198	305.418	130.779	336.687	362.131	31.125
	2005	(ktoe)	1.182.403	306.602	131.703	332.262	364.711	30.931
	2006	(ktoe)	1.186.125	303.658	135.816	328.340	372.191	28.952
	2007	(ktoe)	1.164.833	284.516	131.354	330.616	376.826	26.935
	2008	(ktoe)	1.168.635	296.632	138.122	317.887	374.269	26.286
EU-27	1990-2008	(%)	9,45%	12,83%	28,89%	-13,04%	33,00%	-20,49%
	1999-2008	(%)	4,96%	3,10%	13,17%	-1,35%	10,41%	-11,81%
	2004-2008	(%)	-1,06%	-2,88%	5,61%	-5,58%	3,35%	-15,55%
EU-15	1990-2008	(%)	16,01%	15,32%	32,22%	0,32%	29,75%	-3,68%
	1999-2008	(%)	4,42%	4,53%	11,90%	-1,03%	6,52%	-7,29%
	2004-2008	(%)	-1,65%	-3,18%	6,09%	-5,40%	1,02%	-16,18%
NMS-12	1990-2008	(%)	-17,96%	1,36%	12,35%	-49,05%	63,26%	-51,29%
	1999-2008	(%)	8,32%	-3,83%	21,23%	-3,02%	51,41%	-25,06%
	2004-2008	(%)	2,54%	-1,22%	2,92%	-6,54%	24,69%	-13,14%



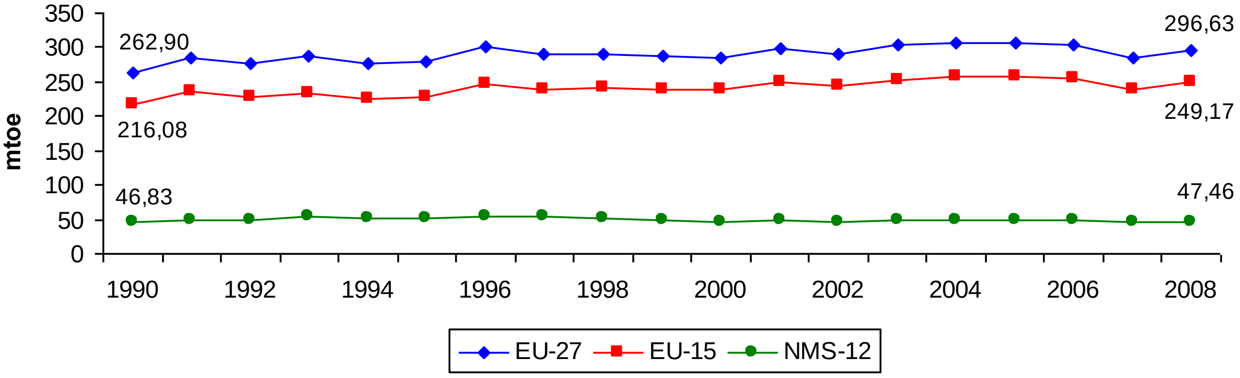
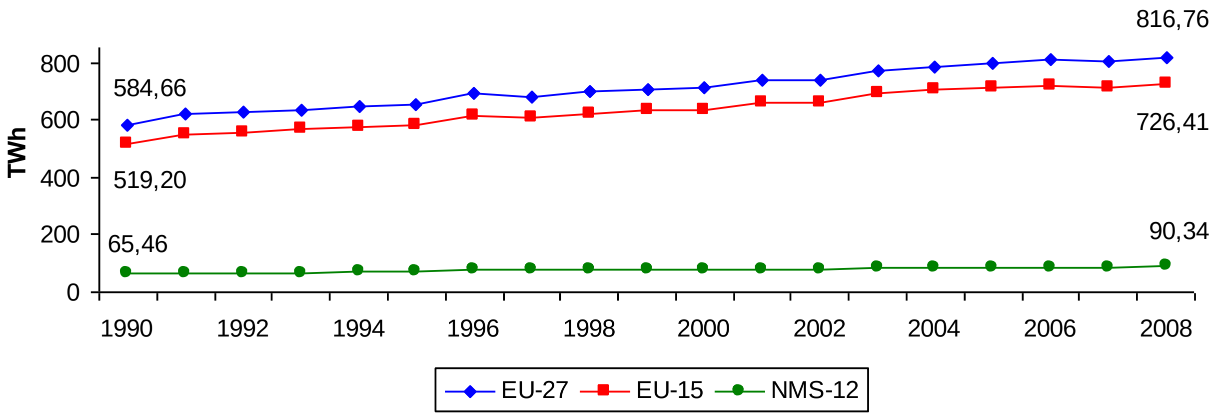


Table 2 EU-27 Final electricity consumption (source Eurostat, JRC)

			Final	Residential	Services	Industry	Transport	Agriculture
EU-27	gwh	1990	2.140.698	584.657	431.154	978.696	62.687	55.948
	gwh	1999	2.440.931	708.070	588.540	1.020.142	68.903	46.996
	gwh	2000	2.516.599	711.200	612.826	1.068.745	71.048	47.465
	gwh	2001	2.592.350	736.755	639.248	1.088.981	71.249	47.808
	gwh	2002	2.600.187	740.402	638.618	1.092.384	71.612	47.050
	gwh	2003	2.668.202	773.814	667.445	1.102.239	72.288	45.325
	gwh	2004	2.723.399	786.673	683.626	1.126.794	72.823	46.943
	gwh	2005	2.762.951	797.706	702.053	1.135.679	73.881	48.247
	gwh	2006	2.823.713	809.062	756.620	1.132.184	70.819	49.320
	gwh	2007	2.843.553	802.485	762.562	1.152.381	70.428	49.207
	gwh	2008	2.855.561	816.756	752.693	1.145.102	71.439	52.844
EU-27	gwh	1990-2008	33,39%	39,70%	74,58%	17,00%	13,96%	-5,55%
	gwh	1999-2008	16,99%	15,35%	27,89%	12,25%	3,68%	12,44%
	gwh	2004-2008	4,85%	3,82%	10,10%	1,62%	-1,90%	12,57%
EU-15	gwh	1990-2008	38,44%	39,91%	67,34%	24,93%	33,69%	53,85%
	gwh	1999-2008	16,28%	15,04%	25,26%	11,39%	7,22%	27,27%
	gwh	2004-2008	4,14%	3,20%	7,63%	1,39%	-0,46%	13,70%
NMS-12	gwh	1990-2008	5,57%	38,02%	142,58%	-19,87%	13,96%	-78,60%
	gwh	1999-2008	22,34%	17,93%	48,04%	18,86%	3,68%	-44,60%
	gwh	2004-2008	10,29%	9,16%	29,32%	3,37%	-1,90%	3,49%

Between 2004 and 2008 final electricity consumption in the EU-27 grew by 4.85%, by 3.82% in the residential sector and by 10.10% in the industry sector. Final electricity consumption in the NMS-12 grew by 10.28% during the same time, by 9.16% in the residential sector. Over the last two decades (1990-2008) EU-27 electricity consumption grew by 33.39%, and by almost 40% in the residential sector (39.70%). In the new member states, final electricity consumption increased by 5.57% between 1990 and 2008. The biggest increase in consumption in the NMS-12 can be found in the services sector (142.64%) whereas there was a decrease in electricity consumption in the industry, transport and agricultural sector. The consumption of the residential sector grew by 38.02% which is comparable to the increase of the EU-17 and EU-15 (39.91%). In the period between 2004 and 2008 final electricity consumption in the NMS-12 grew by 10.28% whereas it only grew by 4.85% in the EU-27 and by 4.14% in the EU-15. This is similar to the consumption pattern in the residential period. Between 2004 and 2008 electricity consumption in the NMS-12 grew by 9.16% and by only 3.82% in the EU-27 and 3.20% in the EU-15.



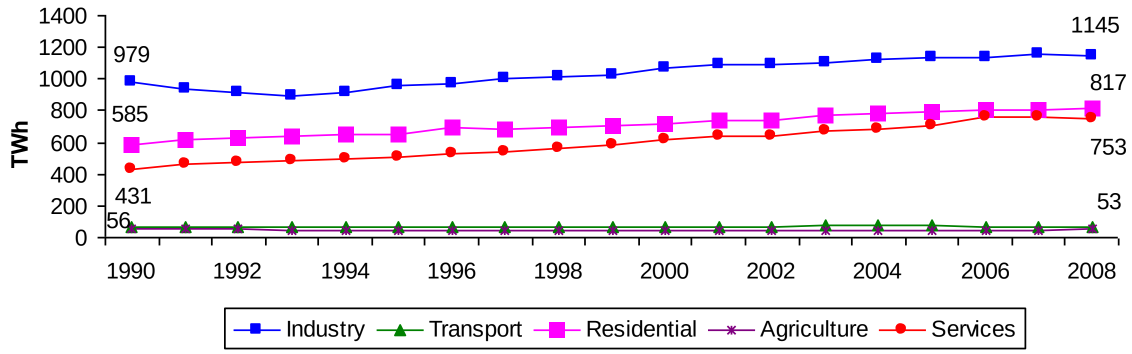
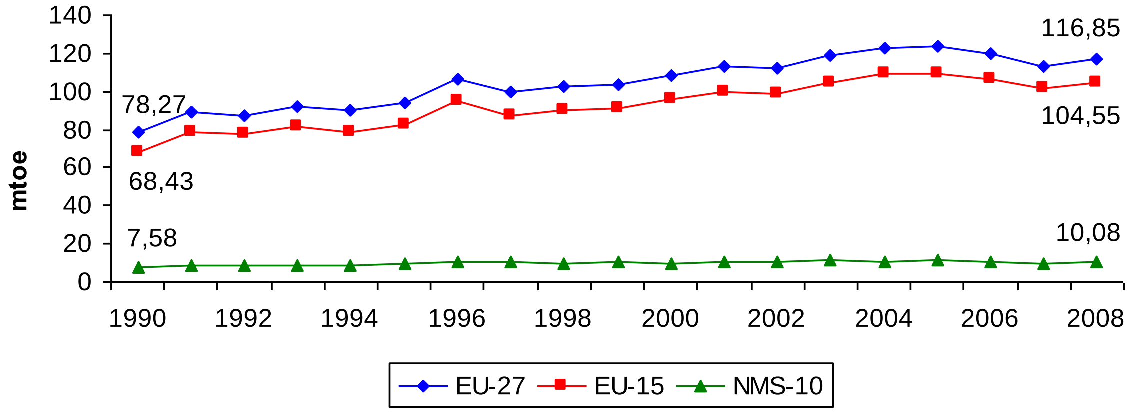


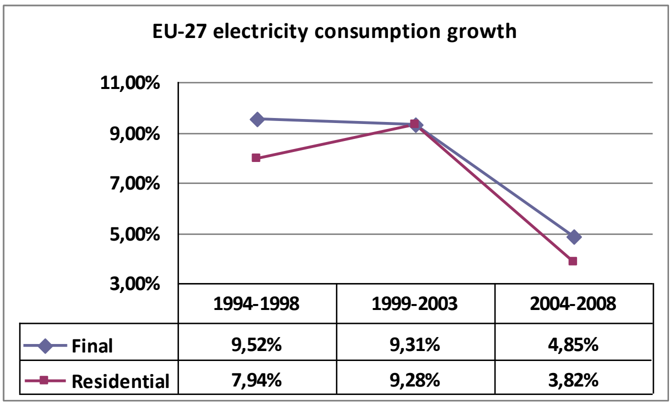
Table 3 EU-27 Final gas consumption (source: Eurostat, JRC)

			Final	Residential	Services	Industry
EU-27						
	1990	(ktoe)	227.403	78.267	26.022	112.006
	1991	(ktoe)	236.364	89.597	29.981	104.117
	1992	(ktoe)	221.855	87.250	29.084	94.666
	1993	(ktoe)	228.275	91.842	29.766	95.274
	1994	(ktoe)	230.424	89.726	32.168	98.754
	1995	(ktoe)	246.501	94.341	35.413	106.280
	1996	(ktoe)	268.066	106.753	39.458	109.654
	1997	(ktoe)	256.366	100.045	37.404	107.459
	1998	(ktoe)	259.198	102.144	39.237	106.514
	1999	(ktoe)	259.840	103.822	38.105	106.656
	2000	(ktoe)	265.588	108.135	34.096	112.098
	2001	(ktoe)	273.075	112.698	37.144	111.847
	2002	(ktoe)	269.135	111.989	35.279	111.145
	2003	(ktoe)	284.438	118.747	39.700	113.855
	2004	(ktoe)	285.827	122.933	41.477	108.858
	2005	(ktoe)	284.211	123.240	41.839	105.980
	2006	(ktoe)	277.947	119.943	42.177	100.959
	2007	(ktoe)	268.496	113.246	38.993	102.568
	2008	(ktoe)	269.116	116.850	42.989	97.049
EU-27	1990-2008	(%)	18,34%	49,30%	65,20%	-13,35%
	1999-2008	(%)	3,57%	12,55%	12,82%	-9,01%
	2004-2008	(%)	-5,85%	-4,95%	3,65%	-10,85%
EU-15	1990-2008	(%)	31,16%	52,78%	62,80%	4,27%
	1999-2008	(%)	3,65%	14,23%	12,74%	-10,76%
	2004-2008	(%)	-5,85%	-4,61%	6,65%	-12,22%
NMS-10	1990-2008	(%)	1,53%	32,97%	56,18%	-26,57%
	1999-2008	(%)	2,60%	-1,86%	4,88%	5,97%
	2004-2008	(%)	-5,52%	-6,58%	-14,52%	0,42%



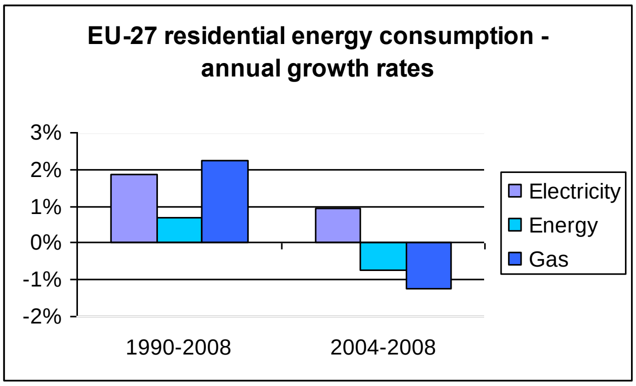
Between 1990 and 2008 the EU-27 final gas consumption decreased by 6.06%, the decrease in the residential sector is 7.88%. Gas consumption also fell in the services and industry sectors during the last decade, by -5.99% and -5.78% respectively. Only between 2004 and 2008 gas consumption in the industry sector grew by 1.59%, in the EU-15 this increase is more notable with 6.65% and 62.80% increase since 1990.

To be able to estimate the effect of energy efficiency policies it is, however, not enough to look at absolute figures and growth rates over a long period of time. If we compare annual growth rates of electricity consumption between 2004 and 2008 with annual growth rates between 1990 and 2003 we see that although consumption is still on the rise, the annual growth rates decrease significantly over time. Final electricity consumption in the EU-27 grew by 9.25% between 1994 and 1998 and by 9.31% between 1999 and 2003. However, in the most recent period between 2004 and 2008 final electricity consumption grew only by 4.85%. This means the electricity consumption growth was only half as big in the latest 4-year period as it was in the two preceding periods. We observe a similar pattern in the EU-27 final residential electricity consumption growth. The consumption grew by 7.94% between 1994 and 1998 and by 9.28% between 1999 and 2003 but only by 3.82% between 2004 and 2008.



This energy efficiency trend can be further illustrated if we not only look at consumption growth over a longer period (e.g. 4 years) but if we look at annual growth rates. In the EU-27 the average annual growth rate of final residential electricity consumption was 1.9% between 1990 and 2008 in comparison to 0.9% between 2004 and 2008. If we look at total energy, the average annual growth rate between 2004 and 2008 becomes even negative, meaning net energy savings were achieved.

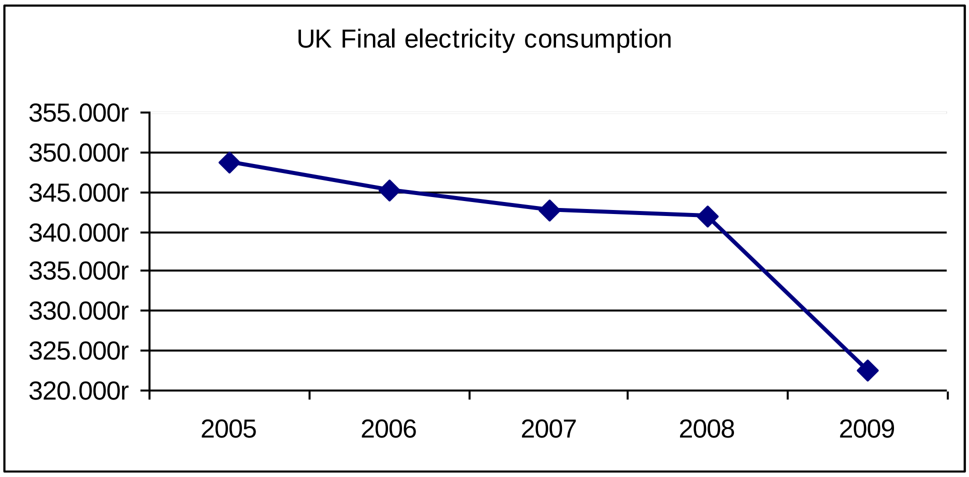
There is a very significant change in the average annual growth rate of final residential gas consumption, going from over 2% between 1990 and 2008 to over -1% between 2004 and 2008.



A reasonable timeline to estimate the impact of EU energy efficiency policies is the year 2005, since from 2005 onwards EU energy efficiency policies were significantly reinforced in order to contribute to the 20-20-20 target. However, it is difficult to estimate the impact of these policies at the given time, only three years after implementation. Nevertheless, energy consumption trends especially in the residential sector seem to indicate that the policies are effective. If we look at more recent data from selected member states, this trend becomes even more profound. The five member states (Denmark, France, Germany, Italy and UK) which consumption patterns are analyzed below were selected because of their data availability for 2009 energy consumption figures. In all of these five countries, final electricity consumption drops significantly in 2009.

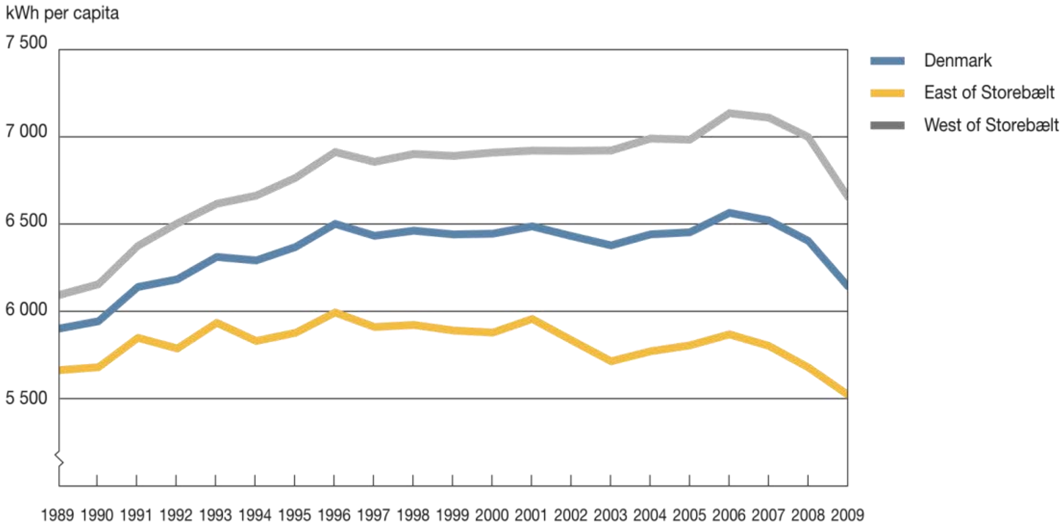
Table 5: Electricity Consumption 2005-2009 in 5 EU countries (source: Eurostat and national statistics)

		Germany	France	Italy	UK	Denmark
2005	(gwh)	141,65	144,55	66,96	125,7	10,45
2006	(gwh)	141,65	147,1	67,64	124,38	10,57
2007	(gwh)	140,03	145,76	67,88	122,76	10,35
2008	(gwh)	139,2	155,61	68,34	125,81	9,66
2009	(gwh)	139,2	154,4	68,9	122,54	9,45



Residential electricity consumption decreased in Denmark, UK and France in 2009. In Germany, final residential electricity consumption did not change in 2009 compared to 2008 but the decrease from 2005 to 2009 is of 1.73 %. Residential electricity consumption in Italy grew from 68.3 gwh in 2008 to

68.9 gwh in 2009 but total final electricity consumption decreased by 6%.[2] The decrease of residential electricity consumption in the UK is 2.6% between 2008 and 2009. In France final residential electricity consumption fell by 6.8% between 2005 and 2009 and by 0.8% between 2008 and 2009.



Looking at the electricity consumption per capita in Denmark, one can see a clear trend towards energy efficiency in recent time. Since 1990, electricity consumption has been on the rise, this trend changed after 2005 when electricity consumption per capita started to decrease. Between 2008 and 2009 the curve became steeper meaning energy efficiency has been even more profound in the most recent time.

2. Factors influencing energy consumption and energy efficiency trends

Energy consumption is influenced by many factors. It is therefore important when evaluating energy efficiency policies to monitor the developments and trends of these factors. These included weather pattern (monitored through actual heating degree days), population trends, economic development (GDP growth), number of households and dwellings, and energy tariffs.

Comparing the last three years (2006, 2007 and 2008) in the consumption tables above, we find a notable reduction in energy consumption in 2007. In 2008 energy consumption is again slightly on the rise compared to the figures of 2007 but still below the figures of 2006. This pattern can be explained by the relatively warm weather in 2007. The actual heating degrees in the EU-27 in 2007 were 2943 compared to 3038 in 2006 and 3008 in 2008. In most years actual heating degree days in the EU-27 exceeded 3000.

2

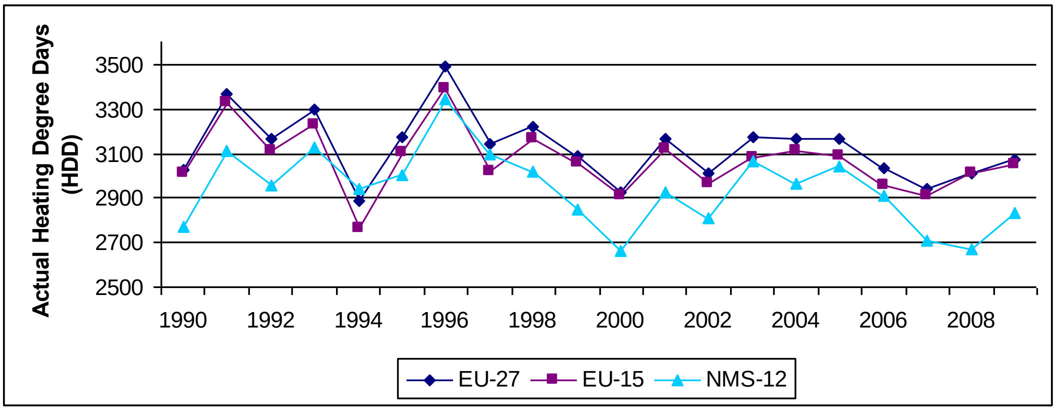
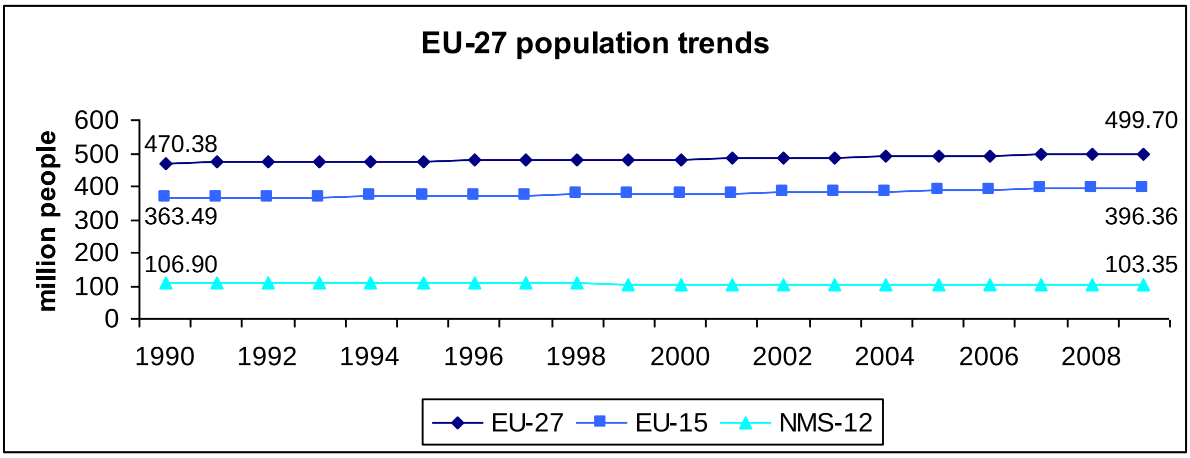
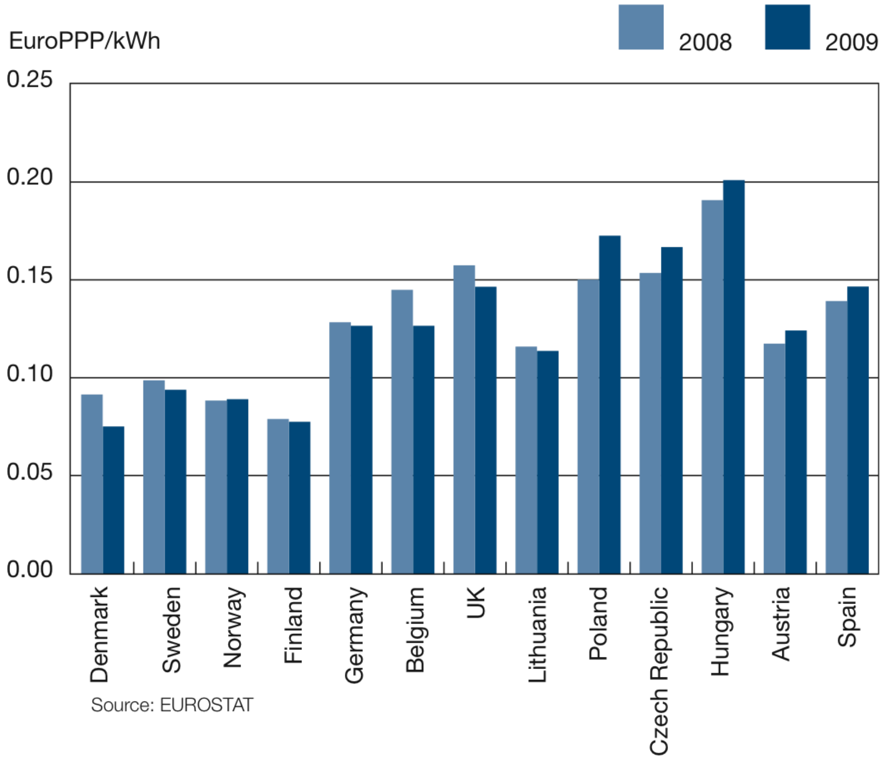


Table 4: Actual Heating Degree Days in the EU-27

	EU-27	EU-15	NMS-12
1990	3029,659	3012,621	2774,42
1999	3086,200	3054,140	2846,37
2000	2926,239	2911,387	2664,23
2001	3164,371	3116,265	2924,40
2002	3013,225	2966,685	2808,69
2003	3172,193	3077,514	3068,64
2004	3163,239	3114,977	2967,43
2005	3162,339	3085,417	3039,68
2006	3038,301	2957,167	2913,34
2007	2943,226	2912,991	2707,38
2008	3007,747	3009,615	2667,38

Population growth can have a significant impact on energy consumption. In the EU-27 population grew by 6.23% during the last 30 years (from 470.38 mio. in 1990 to 499.7 mio. in 2009). In the NMS-12 the trend was the opposite, population decreased from 106.9 mio. in 1990 to 103.35 mio. people in 2009. The increase in population in the EU-27 was therefore evoked by the high growth rates in the EU-15. From 363.49 mio people in 1990 population grew by 9.04% to 396.36 mio. in 2009.

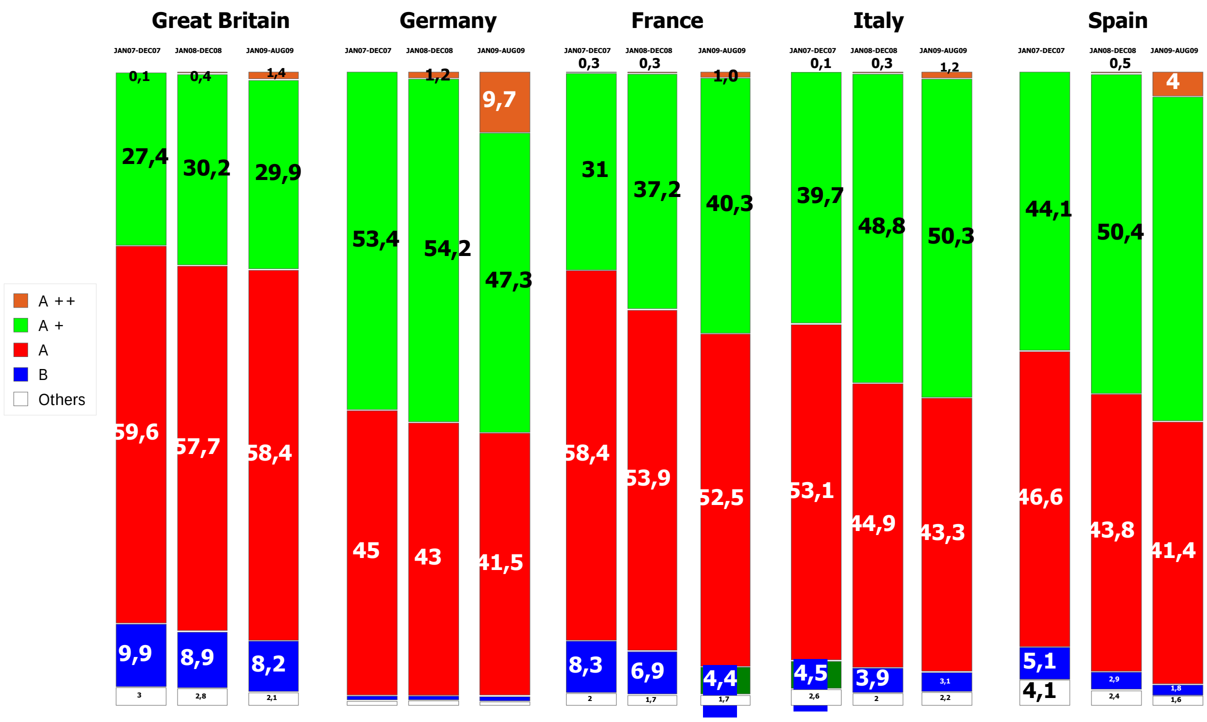




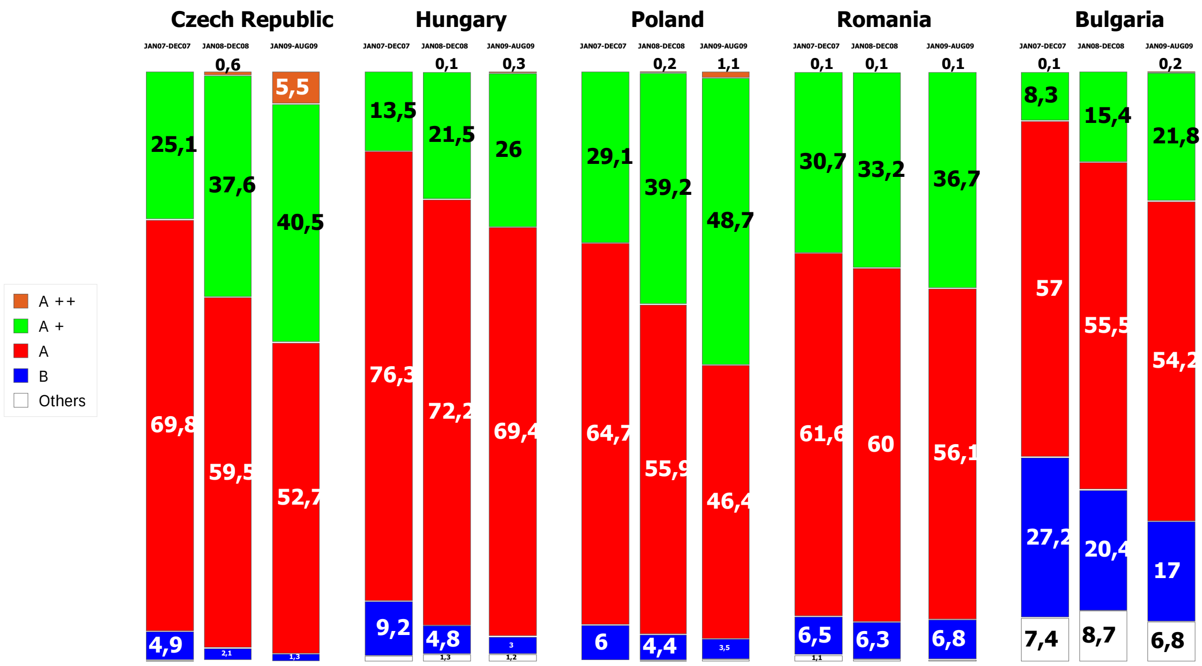
Electricity tariffs vary across Europe. We can find substantially lower tariffs in the Nordic countries compared to the rest of Europe. This fact is linked to the relatively higher electricity consumption in these countries. Between 2008 and 2009 there is no clear trend of whether tariffs rise or fall across Europe. There are only slight changes in the tariffs, and these changes go in both directions. *(Comment for the reviewer: I will add a figure with price developments for the EU for the last 10 years at least to have a better estimate of the influence of prices on energy consumption).*

3. Recent energy efficiency trends and policy developments

Recent surveys and figures show that especially the labelling of household appliances is an effective energy efficiency policy that is widely accepted by consumers around Europe. There is a significant increase in sales of energy efficient household appliances due to eco-design labels during the last years. In 2007 the sales of A+ (then the most efficient class) washing machines in Germany was 53.4% of overall sales. In 2009 it was 47.3% of overall sales but 9.7% were A++ washing machines. The two highest efficiency classes accounted for 57% of overall sales while sales of washing machines labelled B was negligible and the ones labelled A was of 41.5% (decreased from 45% in 2007). In Italy the sales of A+ labelled machines went from 39.7% in 2007 to 50.3% in 2009 plus 1.2% (increased from 0.1% in 2007) of overall sales were A++ washing machines. In the Netherlands A++ labelled washing machines accounted for 6.1% of overall sales (0% in 2007) and 58.4% of overall sales were labelled A+ (45.7% in 2007). The figures in other European countries are similar to those described. In the group of the NMS-12 sales of A+ labelled machines also increased significantly. However, the A++ labelled machines do not account for an important portion of overall sales yet. An exception is the Czech Republic where 4.7% of overall washing machine sales were labelled A++ in 2009.



Similar to the developments in the sales of washing machines there are significant increases in sales of energy efficient cooling appliances and air conditioners. Countries with a high percentage of A++ labelled cooling appliances are Germany (14.5%), Austria (6.8%), the Netherlands (4.8%), Belgium (4.5%) and Czech Republic (5.5%). The sales of A+ labelled cooling appliances increased significantly in all countries, whereas the percentage of A and B labelled sales (less efficient) decreased.



Factors influencing the penetration of energy efficient appliances into national markets in Europe

Sophie Attali (SOWATT), Eric Bush, Anette Michel (Bush Energie)

Abstract

We present the findings of a study prepared for Defra / The market Transformation Programme on the "Factors influencing the penetration of energy efficient electrical appliances into national markets in Europe". The study was finalised in January 2010.
Three main sources of information have been used: market data bought from a specialised marketing company (over 1400 graphs), published and grey literature (70 references), and interviews with key stakeholders (29 interviews).
The study covers seven product categories of domestic appliances bearing the European Energy Label (cold appliances, freezers, washing machines, tumble driers, ovens, dishwashers and air conditioners) and nine European countries, selected for the potential differences they could illustrate: Switzerland (CH), Germany (DE), Denmark (DK), France (FR), United-Kingdom (UK), Italy (IT), the Netherlands (NL), Poland (PL), Portugal (PT).
The considerable volume of information gathered and analyzed shows marked differences between national markets in terms of:

- Market share of efficient appliances and the number of models available for consumers. In summary - high in CH, DE, DK and IT for certain product categories; low in UK and PT
- Purchase price of efficient models: often low in UK and PL; often high in DK, DE and IT
- Electricity prices (purchasing power corrected) – which may be correlated with market shares: high in IT, PL and DE; low in UK and FR

Marked disparities between quantitative and qualitative data have allowed us to develop over 20 hypotheses, which can potentially explain these differences. Influence factors identified relate to energy prices and country structure, the appliance market, consumers' attitudes and policy strategies.

Introduction

This paper presents a study prepared for Defra / The market Transformation Programme on the "*Factors influencing the penetration of energy efficient electrical appliances into national markets in Europe*". The study was finalised in January 2010 [1].

The European market for electrical appliances seems to be governed by a paradox. On the one hand, many elements of the supply chain drive the market towards homogeneity: a few large manufacturing companies are present in all countries and able to supply all countries; products are generally similar from a technical point of view, and the European Energy Label facilitates a standardised approach to energy efficiency labelling throughout Europe. On the other hand, this study reveals very important national differences in terms of the market share and supply strategies for efficient appliances. This paradox can be partly explained by the market structure, which is less international than it initially seems. On the manufacturing side - especially in the white goods sector - sister companies or subsidiaries are often independently managed and, together with retailers, they choose the products they want to sell, influence the marketing of the various brands they manage, and set the price.

Legitimate reasons for national market differences, however, have to be examined through factors specific to each country, such as energy efficiency policies and their enforcement, and electricity prices and purchase price of energy efficient products, as well as cultural anomalies, sensitivities to environmental issues and differences in purchasing power. The European Energy Label has played a crucial role, firstly in forcing manufacturers to recognise the value of energy efficiency and in raising consumers' awareness. But the labelling of appliances *per se* does not seem to be enough to spontaneously shift the market and result in higher market shares for efficient appliances.

The study covers seven product categories of domestic appliances bearing the European Energy Label (light bulbs were excluded because the industry and market structure would have been completely different): Cold appliances, freezers, washing machines, tumble driers, ovens, dishwashers and air conditioners.
Nine European countries were covered, selected for the potential differences they could illustrate in terms of size, regions (Southern, versus Northern Europe, versus Eastern Europe), national product policies (e.g. use of rebates or not), population sensitivity to environmental issues, differences in electricity prices, etc.: Switzerland (CH), Germany (DE), Denmark (DK), France (FR), United-Kingdom (UK), Italy (IT), The Netherlands (NL), Poland (PL), Portugal (PT)

Three main sources of information have been used: market data bought from a specialised marketing company (over 1400 graphs), published and grey literature (70 references), and interviews with key stakeholders (29 interviews). (See the study for detailed definitions of products and sources, mainly GfK and EFA for CH and recognised journals for publications).

The study consists of three main sections and two appendices

- Market share of efficient appliances: Efficiency class distribution of the appliances between 2005 and 2009 for the nine countries covered by the study, country-by-country comparison of sales distribution and diversity of efficient appliance offerings across different markets.
- Influencing factors: Twenty-eight identified factors influencing the penetration of energy efficient appliances into national markets were identified in the research phase (barrier factors and supportive factors). Each factor's effects are described, the evidence presented and short policy recommendations are made. Results from interviews largely helped to determine the influencing factors.
- Policy instruments: Seventeen different policy instruments aimed at increasing market share of energy efficient domestic appliances are presented. A description and overview of their implementation in each of the relevant countries is provided for each instrument, and pros and cons are discussed, based on findings from interviews and, more significantly, from the literature review.
- Appendix A contains a country comparison matrix. It provides an overview of the main contextual elements, product and price anomalies across all product categories covered as well as existing policy instruments across all studied countries and in the EU.
- Appendix B presents a list of nearly 70 references and links to relevant country-specific and European websites.

Striking differences between national market developments

Table 1 shows estimates of maximum savings potential (per unit) when inefficient appliances are replaced with very efficient ones. The table shows, for example, that replacing cooling appliances (A++ instead of B) leads to large savings (2550 kWh per appliance over 10 years); while virtually no savings are currently likely with dishwashers, as nearly all models are of similar efficiency.

Appliance Category	Criteria	Efficient kWh/a	Inefficient kWh/a	Potential kWh over 10 years
Cold appliances	A++ versus B	170	425	2 550
Ovens and cookers	A versus B	115	143	280
Dishwashers	A versus A	260	260	0
Washing machines	A+ versus B	170	230	400
Driers	A versus C	320	640	3 200
Air conditioners	A versus D	500	615	1 150

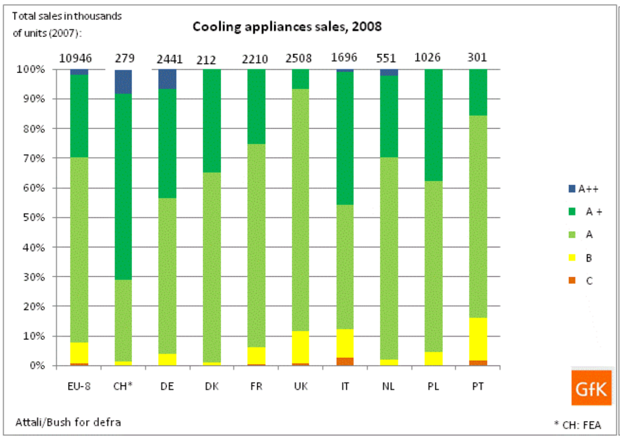
Table 1 - Rough estimation of maximum savings potential per unit[1]

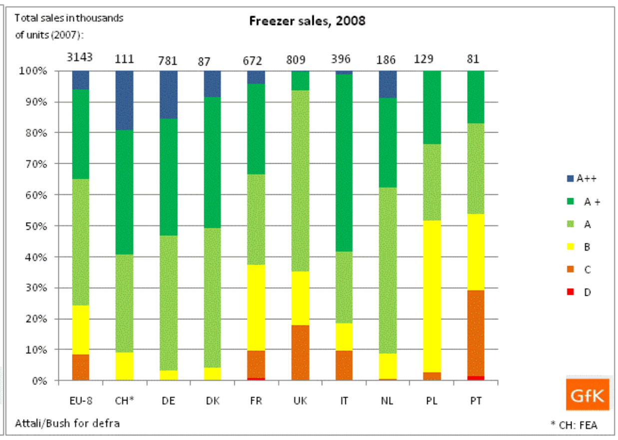
Keeping these orders of magnitude in mind, the graphs provided below show there is still room for national context and policies to influence markets. Although the nine countries studied are governed by the same basic legislation on energy labelling and minimum energy performance standards, and are supplied by the same manufacturers, there are marked national differences in the market share of efficient models across all product categories.

The full study shows specific examples illustrating differences between countries in terms of market penetration of efficient models, and market developments between 2004 and 2008, but the graphs below show the sales' share for 2008 (10 months, from January to October). For the comparisons between countries, the numbers given are those of 2007, the last year for which full data was available

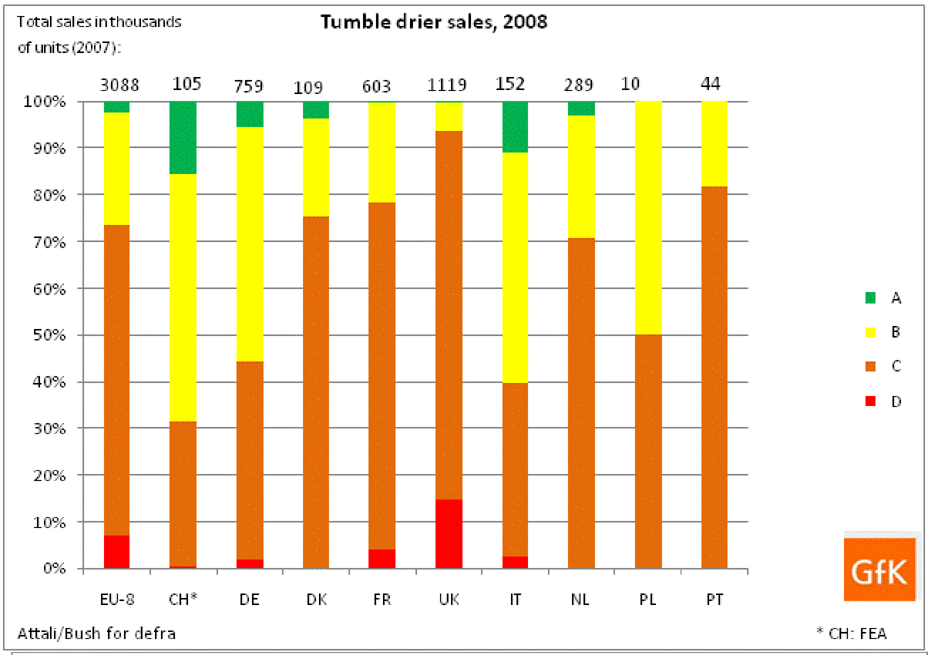
Many comments can be deduced from these graphs. We just mean to show differences on the common European market, for example that:

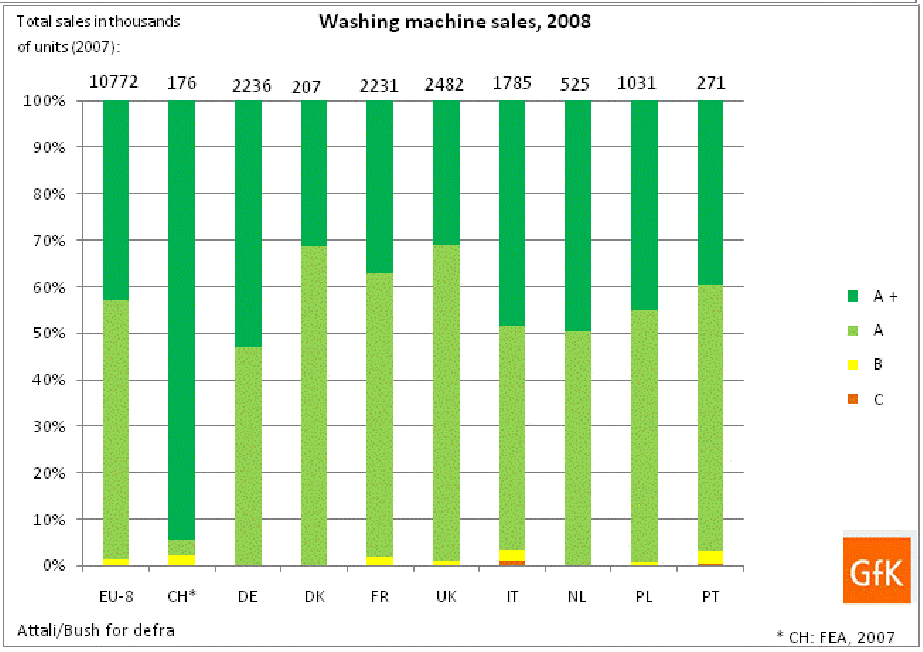
- For cooling appliances, UK has a market share of A+ models of less than 10% whereas it reaches round 45% in IT and DE
- For freezers, A++ models are present on the market, with up to 10 and 20% market share in DK and CH, whereas they are totally absent from other national markets
- Same situation for driers, where the A class is present in some countries (15% in CH, 5% in DE) and absent from others
- For washing machines and ovens, the market is more homogeneous, however showing a market share of 95% for A+ washing machines models in CH compared to 35% in France or 30% in the UK, and whereas many countries show more than 60% A models for ovens, UK shows only around 45%
- For air conditioners, hot climate Portugal has a lower market share of class-A models than cooler Germany

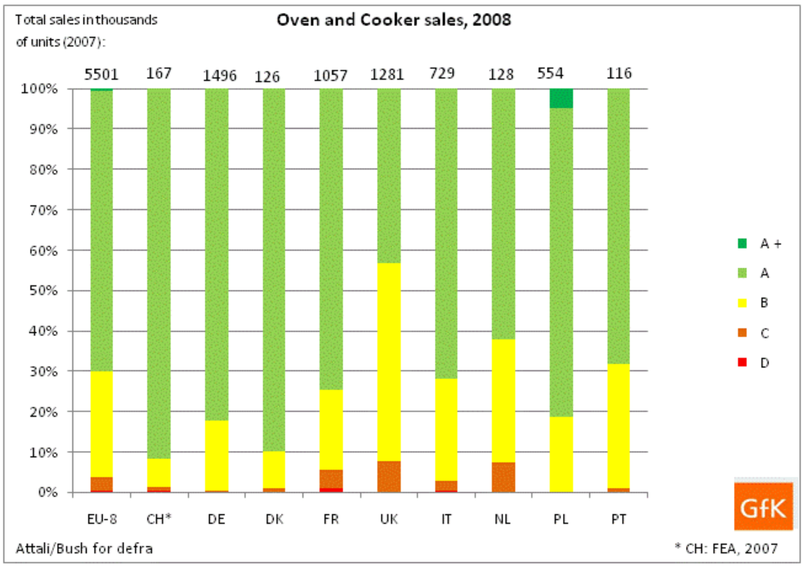




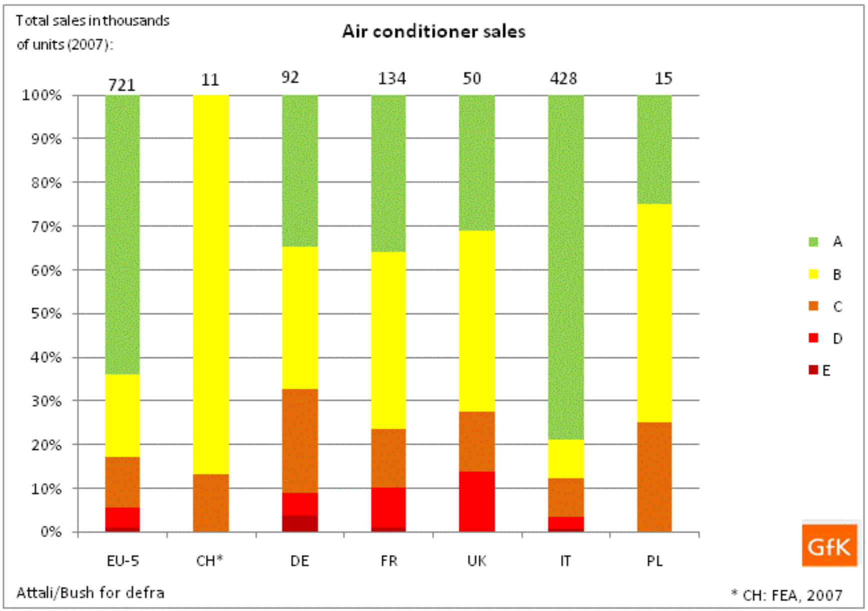
[1] The table shows electricity consumption of very efficient appliances (according to energy label and www.topten.info), of inefficient appliances (according to energy label) per year and the difference between them during their (assumed) life cycle of 10 years (in 2009).







Note: A+ cookers do not actually exist. The reference to A+ models above reflects a misuse of the energy label by one manufacturer in Poland.



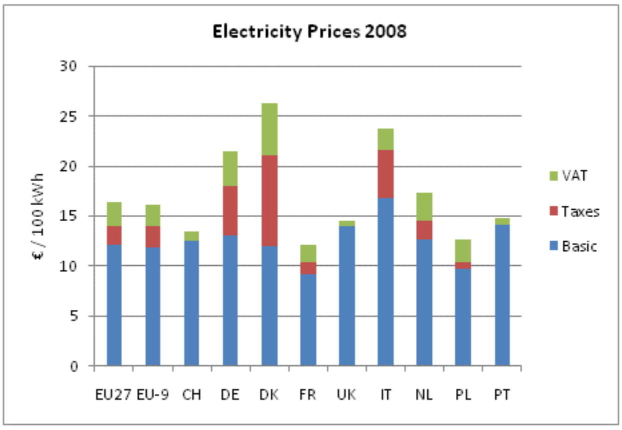
Dishwashers are currently an exception, because as nearly all products are A-labelled, there is no information about national differences available.

Factors influencing the penetration of efficient appliances on national markets

Marked disparities between quantitative and qualitative data have allowed us to develop over 20 hypotheses which can potentially explain the fact that there are differences on national markets even though legislative background and the suppliers are the same all over Europe. These factors have been identified and classified according to the following themes: energy prices and country structure; the appliance market, consumers' attitudes and policy. They are briefly presented hereafter with some illustrating graphs.

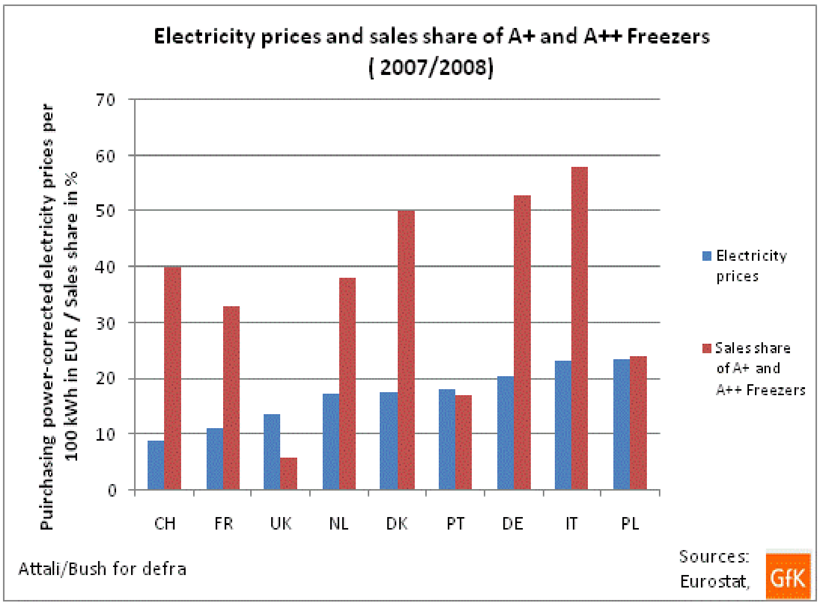
Factors relating to **energy prices** and **country structure** include:

- Electricity tariffs and their structure, impacting both consumers' and utility companies' perceptions of the economic value of energy efficient appliances;
- The presence of institutions that have a mandate to promote energy efficiency and thus promote efficient appliances;
- The existence of large-scale buyers able to influence the market;
- The impact of the size of the country, which determines the number of stakeholders and creates possible difficulties with control mechanisms within large territories.



For example, electricity prices vary by a factor of two between countries. Market shares of efficient products are correlated to a certain extent (see DK, IT and DE).

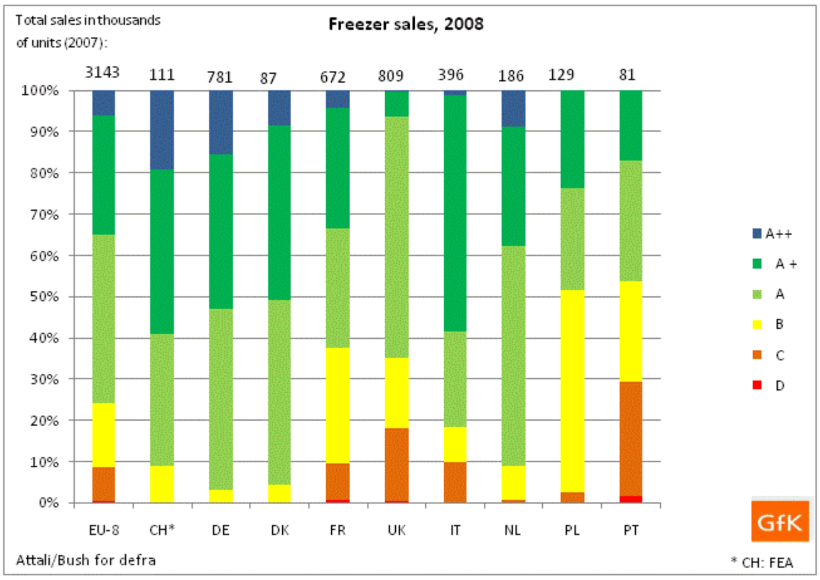
(Sources: For EU: Eurostat 1st sem. 2008 (IT 2nd sem. 2007), CH: http://strompreise.preisueberwacher.ch)

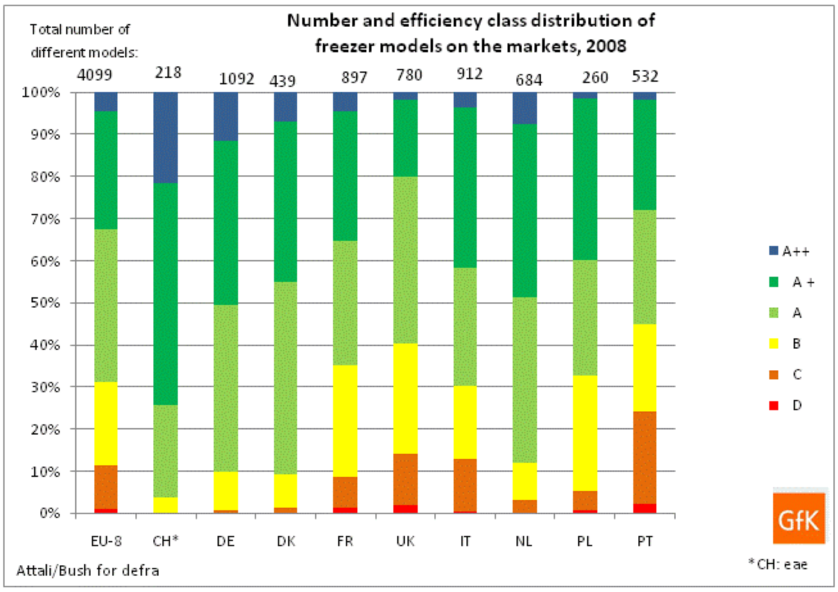


Factors relating to **the appliance market** include:

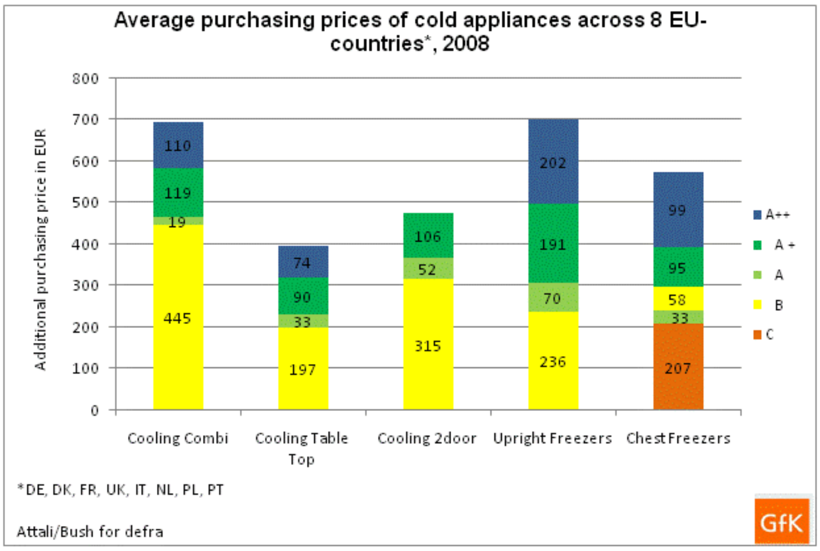
- The type of market – are retailers looking for greater margins and therefore trying to sell efficient models, or are they focused on volume and low-end products? Is the market particularly challenging because of fierce price competition?;
- The range or diversity providing enough/not enough choice to consumers;
- Purchasing prices which are a clear barrier to the wide take-up of energy efficient models. Both the relatively high prices of energy efficient models and low average prices in general (low prices tending to denigrate the offer and increase the focus on price) can be barriers;
- The structure of the retail sector (few powerful players versus more numerous smaller retailers) and business models between retailers and manufacturers (range selection, pricing, commission) – which impact on the policies designed to promote efficient appliances.

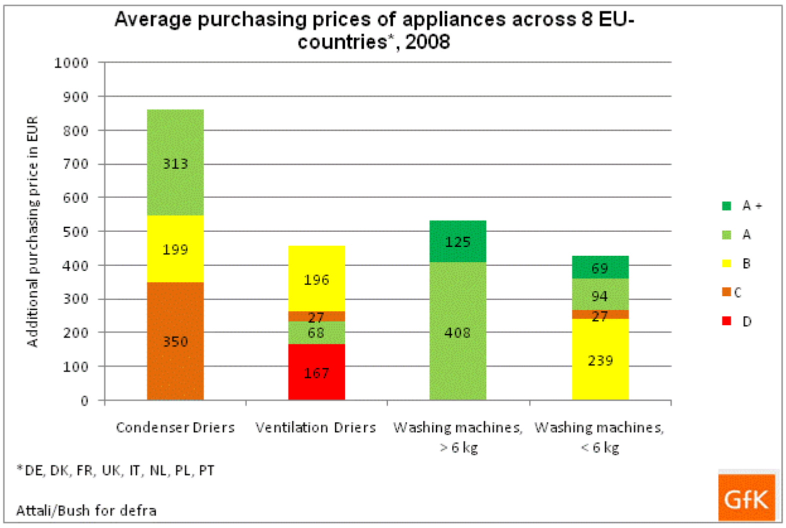
For example, for efficient models: less choice leads to less sales. Even though data regarding products numbers should be read with caution (commercial reference tracking is not an easy task), the next 2 graphs on sales figures and model availability show a certain correlation: it is obvious that consumers cannot buy what is not offered, but it is also true that, in general, energy efficient models sell more if the in-store range is large (within A+ and A++ classes).



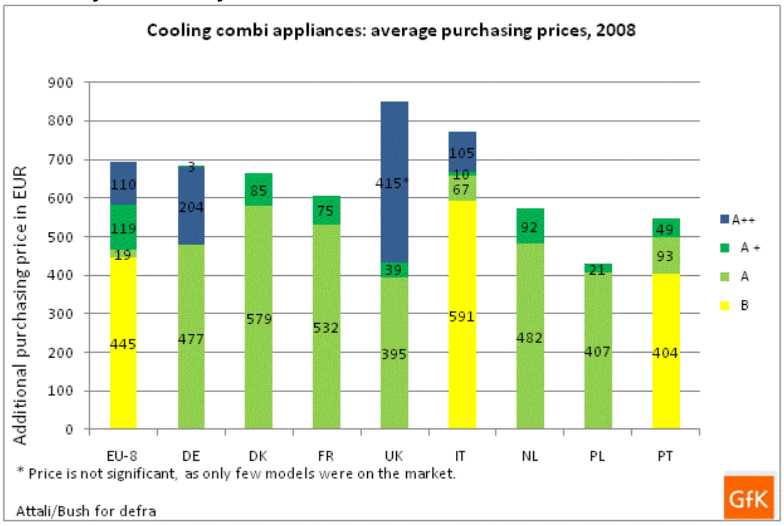


Another example concerns the price of efficient appliances: they are more expensive, even if there are strong variations between countries. In the next two graphs, each bar represents the average price of given appliances for selected countries. For each product, the additional expenses needed to go from one energy class to another is indicated (e.g. in average, for cooling combi which cost 700 € in 2008, there is a 19 € difference between class B and class A, 119 € difference between class A and class A+ and 110 Euros between class A+ and class A++).

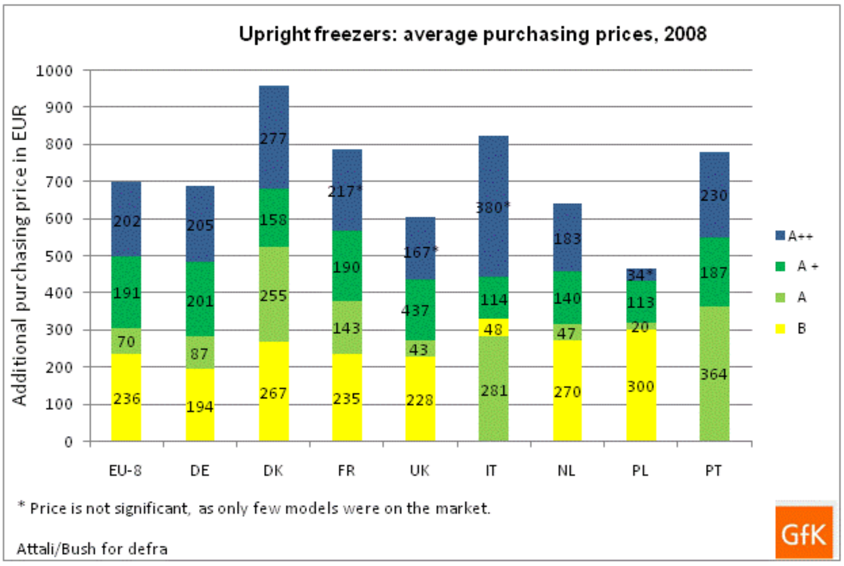




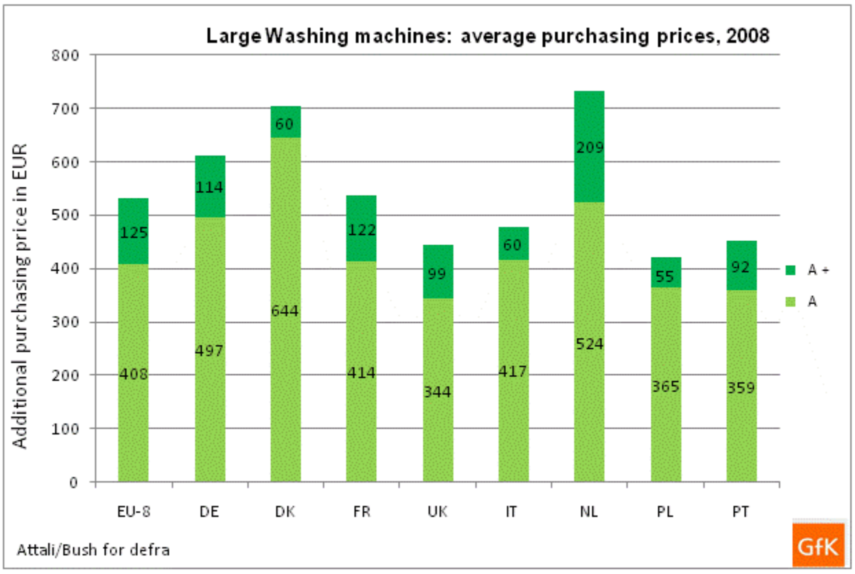
Additional purchase prices for high-efficiency cold appliances (A+ and A++) differ strongly from country to country.



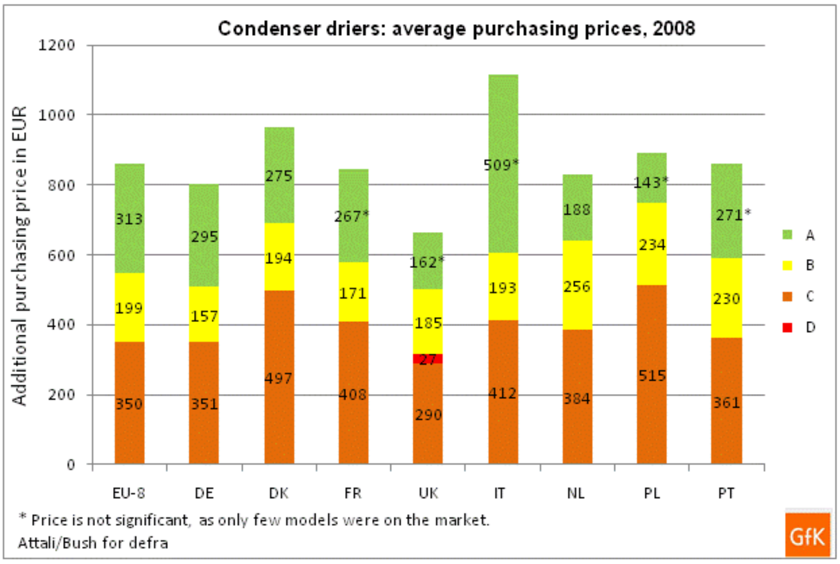
For freezers, price differences between countries are striking. The additional price for A++ is very high.



For washing machines, the striking price difference might be due to different performance levels in different countries, especially with regard to the spinning efficiency.



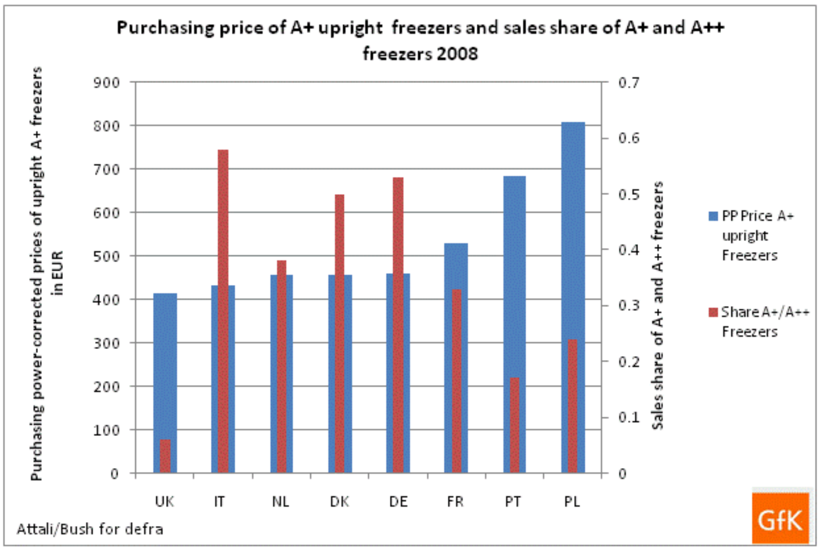
The (still) relatively high purchase price of heat pump driers slows down the breakthrough of profitable energy savings over the life cycle.

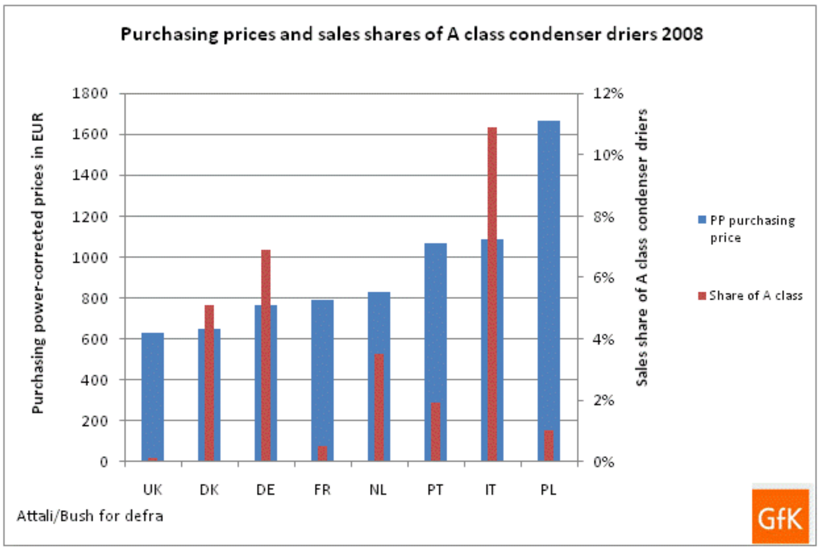


Factors relating to **consumers' attitudes** include:

- Consumers' sensitivity to environmental issues, which can make them well-disposed towards energy efficient models;
- Their desire for brands and trusted products which may (or may not) be particularly energy efficient;
- Their focus on purchase price which can override any other sales promotions and can encourage retailers and manufacturers to enter a downward spiral of low purchasing prices;
- Their level of awareness of energy issues in general and the European Energy Label in particular – the penetration of efficient models being greater when consumers know about the label and relate domestic appliances to energy consumption, lower energy bills and wider issues such as climate change.

For example, attitude towards purchase price is not sufficient to explain market shares of efficient models. Price is always important to consumers but in some countries consumers focus on quality and brand, and only then look for competitive prices (e.g. CH and DE). In other countries, price is the primary criteria but other criteria are also considered (e.g. FR, IT) and for some countries, it is difficult to develop marketing strategies other than by focusing on the purchase price (e.g. UK and PT).





Factors relating to **policy** include:

- Market transparency and the enforcement of regulations – which have an impact on market stakeholders' behaviour;
- The availability of regular national and European market analysis, covering both sales data and detailed market operations – which could positively influence policy design;
- The general context in which the policies are designed: whether background regulation encourages (or discourages) energy efficiency measures; the time frames within which decisions are taken; stakeholders' involvement, and the current economic crisis.

While no single factor can fully explain the reasons for market differences between countries, all have an impact on the policies that address product efficiency.

Policy instruments relating to efficient appliances

The study has also identified 17 policy instruments which are used (or where the use of which is under discussion) to reform the various domestic appliance markets. These instruments are classified in four main group, described and discussed in the study:

Regulatory measures
  - Informative labels;
  - Minimum energy performance standards (MEPS);
  - Enforcement activities – product testing and correct labelling in shops;
  - Taxes on electricity prices;
  - Energy saving and CO_2 reduction obligations on energy suppliers
- **Financial incentives**
  - Subsidies targeting consumers, retailers, manufacturers;
  - Support for Research and Development;
  - Other types of subsidies
- **Voluntary measures**
  - Endorsement labels;
  - Information campaigns;
  - Voluntary agreements and programmes;
  - Voluntary target programmes;
  - Training campaigns
- **Other instruments**
  - Data and market analysis;
  - Public procurement;
  - Technology and cooperative procurement;
  - Identification of most efficient products.

Again, no single policy instrument can be described as fully determinant regarding the penetration of efficient appliances on the market, because each of them have pros and cons, and for each of them success is very much linked to their detailed design.

However, the nine countries studied have all implemented different strategies:
- In Denmark and United Kingdom, an explicit product strategy is applied with a comprehensive approach, covering all aspects from market research, to regulation enforcement, national endorsement label, voluntary programmes, etc.
- In France, Germany, Italy, the Netherlands and Switzerland, governments implement many activities but not necessarily within a comprehensive framework.
- In Poland and Portugal, fewer measures are implemented, and/or the scope seems to be more limited.

Conclusion
Sales data are of crucial importance at a national but also at a European level, in order to compare and effectively monitor markets and policies. They show that energy efficient models have very different market shares in the various countries, even when strategies to promote efficient models are similar (policies, training for retailers, information to consumers, etc.). This suggests that contextual factors are of crucial importance: different tax systems, different electricity prices, different stimuli for energy saving, different consumer cultures regarding product preference, sensitivity to environmental issues, etc. Therefore, success also seems to depend on combinations of policy instruments - combinations which should be chosen carefully and tailored to the factors influencing each national market.

Appendix 1 – Details on collected data and definitions
For the EU-countries, GfK[2]-sales data on major domestic appliances covered by the European Energy Label for the years 2004 – 2008 was obtained. For Switzerland, sales data was separately researched from FEA and eae[3]. More than 1 400 GfK-graphs were analysed in the framework of this study. The seven product categories cover the following sub-categories:

2 www.gfk.com

3 Fachverband Elektoapparate Haushalt und Gewerbe Schweiz (FEA), 2007 and energie agentur elektrogeräte (eae)

1. Cooling (also known as "cold") appliances
    - "1 door": refrigerators with one external door, possibly including a small freezer compartment.
    - "2 door": fridge/freezers with two external doors, with a relatively small freezer compartment on top of the larger refrigerator.
    - "Combi": fridge/freezers with two or more external doors, with a rather large freezer compartment at the bottom and a cooling compartment of equal or larger size on top of it. Usually these appliances have one compressor, but can also have two compressors.
    - "Table top": small 1 door refrigerators which can be put under a shelf. They might also have a small freezer compartment inside.
    - "US-Style": large-volume fridge/freezers with two vertical doors, the freezer compartment possibly being narrower than the cooling compartment.
2. Freezers: Upright freezers and Chest freezers
3. Washing machines (also known as "wet" appliances): Small washing machines[4]: for less than 6 kg of laundry and Large washing machines[5]: for 6 kg of laundry or more.
4. Tumble driers
    - Condenser driers: condenser driers condense the humid air, collecting the water.
    - Ventilation (or evacuation) driers: these driers channel the humid air outdoors.
5. Ovens and Cookers
    - Ovens: baking appliances, without hotplates
    - Cookers: one appliance containing hotplates and an oven. The energy label however refers to the oven only.
6. Dishwashers (also known as "wet" appliances): Small dishwashers[6]: for less than 12 place settings and Large dishwashers[6]: for 12 or more place settings.
7. Air conditioners: Mobile air conditioners: air conditioners in one piece and Split air conditioners: with external compressor.

In relation to the literature review, almost 70 published articles covering energy efficient appliances have been examined. Most of the literature was found in major, well regarded energy journals and books, proceedings of targeted conferences (eceee and EEDAL) and pieces of grey literature. The focus was on literature from Europe in order to cover policy instruments applied in Europe, but some more international sources have also been used. As the topic of domestic appliances in Europe is quite specialised, many sources were only of partial relevance. Some sources were not used because their content was outdated.

29 qualitative interviews have been conducted with policy officers, experts and different market stakeholders, between mid January and mid March 2009. 20 of these experts were interviewed face-to-face, and nine by phone. 14 interviews were held with policy officers from government and administration, six with experts from the manufacturing industry[7], four with researchers, three with retailers and two with NGO experts. The interviewees represent all countries covered by the study: CH (1), DE (2), DK (4), FR (2), UK (5), IT (6), NL (1), PL (3), PT (3), International (2).

Reference

[1] Factors influencing the penetration of energy efficient electrical appliances into national markets in Europe, a report for Defra / MTP prepared by SOWATT (Sophie Attali) and Bush Energie (Eric Bush & Anette Michel), http://efficient-products.defra.gov.uk/cms/library-publications/

---

4 This is a marketing definition, different from the technical classification of washing machine sizes: from a technical point of view, small washing machines would cover 4kg of laundry or less, normal size machines 5 – 7 kg and large washing machines 8 - 10 kg.

5 This is a marketing definition, dishwashers for 12 place settings are generally considered of "normal" size.

6 The wording "Manufacturer" in this study covers both producers and importers.

How much did we actually save? – a long-term evaluation of appliance standards and labels

Kevin Lane, Lloyd Harrington, Paul Ryan

Kevin Lane (Oxford) Ltd, Energy Efficient Strategies, EnergyConsult

Abstract

Mandatory energy labelling and minimum energy efficiency performance standards have been introduced in many economies around the world. Their use is expanding due to their effective delivery of energy savings and mitigation of carbon emissions, in most cases at negative cost to society.

As part of good policy making it is essential to check the reliability of the claims being made by policy measures after they are implemented. However, very few robust long-term (ex-post) evaluations have been undertaken by policy makers on appliance programmes. Most programmes rely on forward looking (ex-ante) impact appraisal estimates for the size of their claimed savings but rarely do they go back and verify whether these projected savings actually occurred (and if not, why not).

Two teams in Australia have recently undertaken such a long-term evaluation, which aimed to attribute the savings to a series of energy policy measures introduced since the mid-1980s, and also perform an assessment on purchase price and product availability (consumer choice). The two studies working in parallel developed and employed a common methodological approach and covered household refrigeration and household air conditioners, which together represent a significant segment of the products covered in the residential sector.

Both studies showed that significant energy savings and carbon emissions reductions have already been achieved through energy programmes and that the savings actually achieved were larger than the original ex-ante estimates had suggested. These savings were achieved with little or no observable impact on the average purchase price, whilst the number of models on the market has not been affected (in fact the number of available models increased with increasing levels of regulations).

Such an analysis is not trivial: the approach used was to develop bottom-up stock models with sales data (matched with energy attributes) over the entire period since the policy measures were introduced, then develop counterfactual scenarios to attribute the impact of each individual policy measure. Changes in actual size, features and product type were taken into account to provide updated (ex-post) estimates of energy savings. Furthermore, a decomposition approach was developed to explain why the original appraisal energy saving estimates was different to the current evaluation estimate (eg larger products, more sales).

This paper summarises the findings of two studies, though the main focus is on the techniques used to address issues with studies of this type, and to propose approaches to developing counterfactual baselines and (changes in expected savings) decomposition analyses.

Introduction

Mandatory energy labelling and minimum energy efficiency performance standards have been introduced in many economies around the world, and their use is expanding due to their effective delivery of energy savings and mitigation of carbon emissions, and at little or even negative cost to society.

As part of good policy making it is essential to check the reliability of the claims being made by policy measures. However, very few robust long-term (ex-post) evaluations have been undertaken by policy makers on appliance programmes. Most programmes rely on (ex-ante) impact appraisal estimates for the size of their claimed savings but rarely do they go back and verify whether these savings actually occurred. In addition, to estimating the difference between the 'predicted' and 'actual' savings it is useful to understand the underlying reasons for any differences. A better understanding of factors that are likely to change over time will assist in the development of improved and more robust future ex-ante forecasts and estimates.

Two teams in Australia have recently undertaken such a long-term evaluation, which aimed to attribute the savings to a series of energy policy measures introduced since the mid-1980s. In addition, they also perform an assessment on product purchase price and product availability (consumer choice). The two studies, which covered household refrigeration and household air conditioners, working parallel developed and employed a common methodology [1, 2].

This paper is structured by providing an overview of each of the studies first, and then it documents the approaches used and the lessons learned.

Key findings from two recent evaluation studies

Refrigeration impacts

The evaluation analysis shows that Australian energy efficiency policies for household refrigeration products have reduced energy consumption significantly, even more than previously estimated. By the end of 2009, the annual energy savings due to all policy measures on refrigerators was around 5.9 TWh/year. To put this into perspective, this represents a reduction in energy consumption of 46% for refrigerators and freezers in 2010, in the absence of energy labelling and MEPS. These savings are today equivalent to over 8% of total residential electricity consumption in Australia in 2010. Most of this (around 4.1 TWh/year) is attributed to energy labels introduced from 1986, thus policies from the late 1990s onwards will have realised an estimated energy savings of around 1.8 TWh/year per annum by 2009. By 2020, the projected energy savings from these later policy measures will more than double, with savings attributed to the policies from the late 1990s onwards at around 4 TWh/year.

The energy savings from these measures can be expressed as financial savings for consumers in energy costs avoided, as well as reductions in greenhouse gas emissions. The 5.9 TWh/year of electricity savings in 2009 was based on a more conservative scenario and represents reduced carbon emission in excess of 5 $MtCO_2$, or about 1% of Australia's total greenhouse gas emissions. These savings represent considerable financial savings to Australian households from reduced electricity bills. By 2009 the policies considered have saved around AU$1billion. These financial savings and carbon emissions reductions will continue to accrue through to 2020 and beyond.

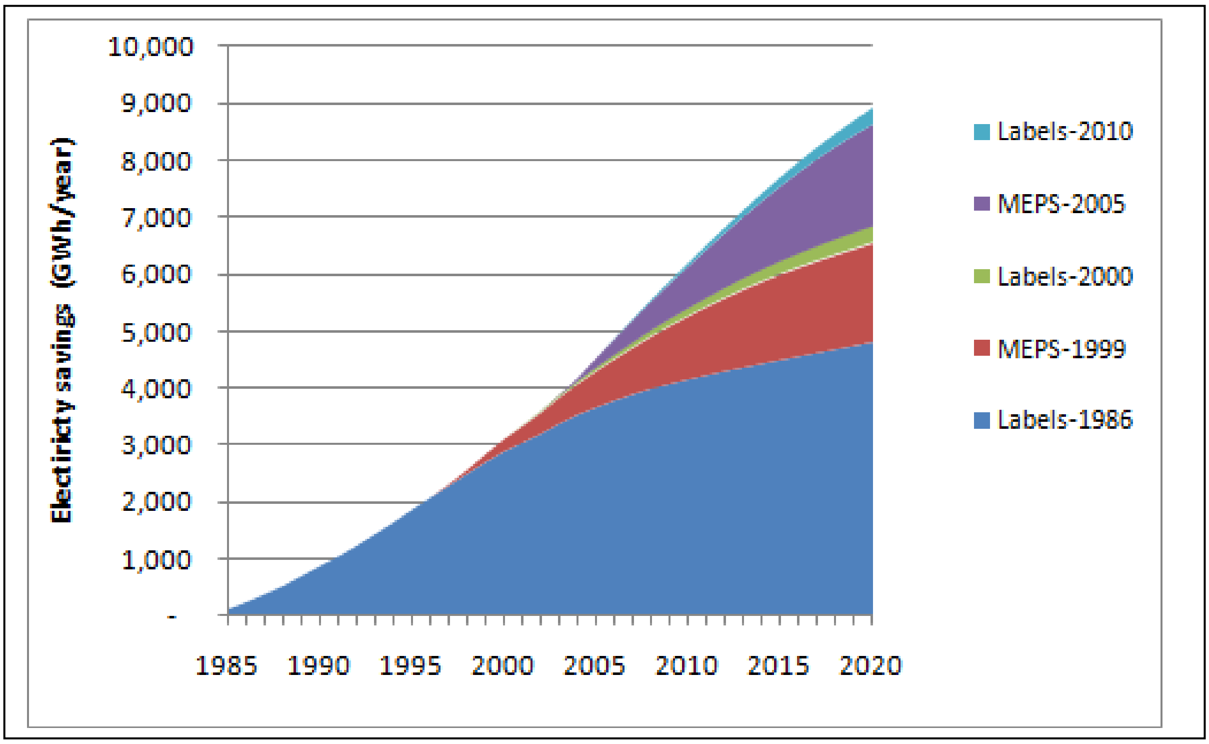


Figure 1: Estimated annual electricity savings from previous refrigerator policy measures

Note: the savings shown are relative to a pre-1986 labels baseline (Baseline, high).

One concern amongst policy makers with increasing the efficiency of appliances sold is that there may be an increase in the purchase price of equipment, even if these costs are ultimately recouped by householders through lower running costs. There are few end-use studies on the link between increased efficiency and purchase price; see for example references [3] through to [8]. The evaluation analysed purchase prices over the observation period (1993 to 2009) found moderate price decreases for Group 1, Group 5B and Group 7 (around 1% per annum decrease in real terms) and fast price decreases: Group 2, Group 5T, Group 5S, Group 6U and Group 6C (2.5% to 11% per annum decrease in real terms). These findings are quite remarkable as they show that over 16 years of full market sales data, the energy consumption of all groups has declined at about 3% per annum over the whole period (energy efficiency has improved at approximately this rate), which is a 40% energy reduction. At the same time, the price of these products fell by 20% to 50% in real terms, based on actual price paid at the retailer. This demonstrates that technology improvements are delivering lower energy at reduced prices, with both parameters falling rapidly over time. While authors like Ellis *et al* [3] have documented trends like this in a number of countries, this flies in the face of conventional wisdom that increased purchase costs are associated with greater product efficiency. Previous market analyses generally found weak or no correlation between market price and efficiency for both refrigerators and air conditioners [9, 10]. Additional evidence for this has been provided by recent US studies on experience of purchase price trends and technology learning curves (for example references [4] and [8]).

The analysis also looked at the price increase assumptions associated with the regulated efficiency increases that were assumed in previous regulatory impact statements and concluded that these assumptions were reasonable (in that the actual price increases were well within the assumed range, but were usually undetectable in the context of rapidly reducing overall prices over time). This does not mean infinite energy savings can be achieved at no cost or negative cost. But it does mean that significant reductions in energy, within the realms of available technology and design approaches, can deliver very low cost energy savings.

One concern often raised with regulatory proposals is that energy efficiency will restrict consumer choice with respect to the number of products on the market. By examining the number of models registered and sold through retailers it is possible to track the number of models sold to consumers (a good surrogate for the number of models available). Even though there are large apparent (energy saving) impacts of the regulatory requirements, it is interesting to note that the number of available models is continuing to increase at quite a rapid rate over time, indicating that consumer choice in terms of models is growing quite quickly, despite the introduction of increasingly stringent regulatory requirements. An open and competitive market is delivering greater consumer choice with lower energy at reduced purchase costs. However, within such a competitive market, surveillance and enforcement is critical if the energy savings from regulatory measures are to be actually realised.

For the 2005 MEPS it was possible to do a detailed decomposition to understand why the evaluation results are different to the appraised (ex-ante) impact assessment done in 2000.

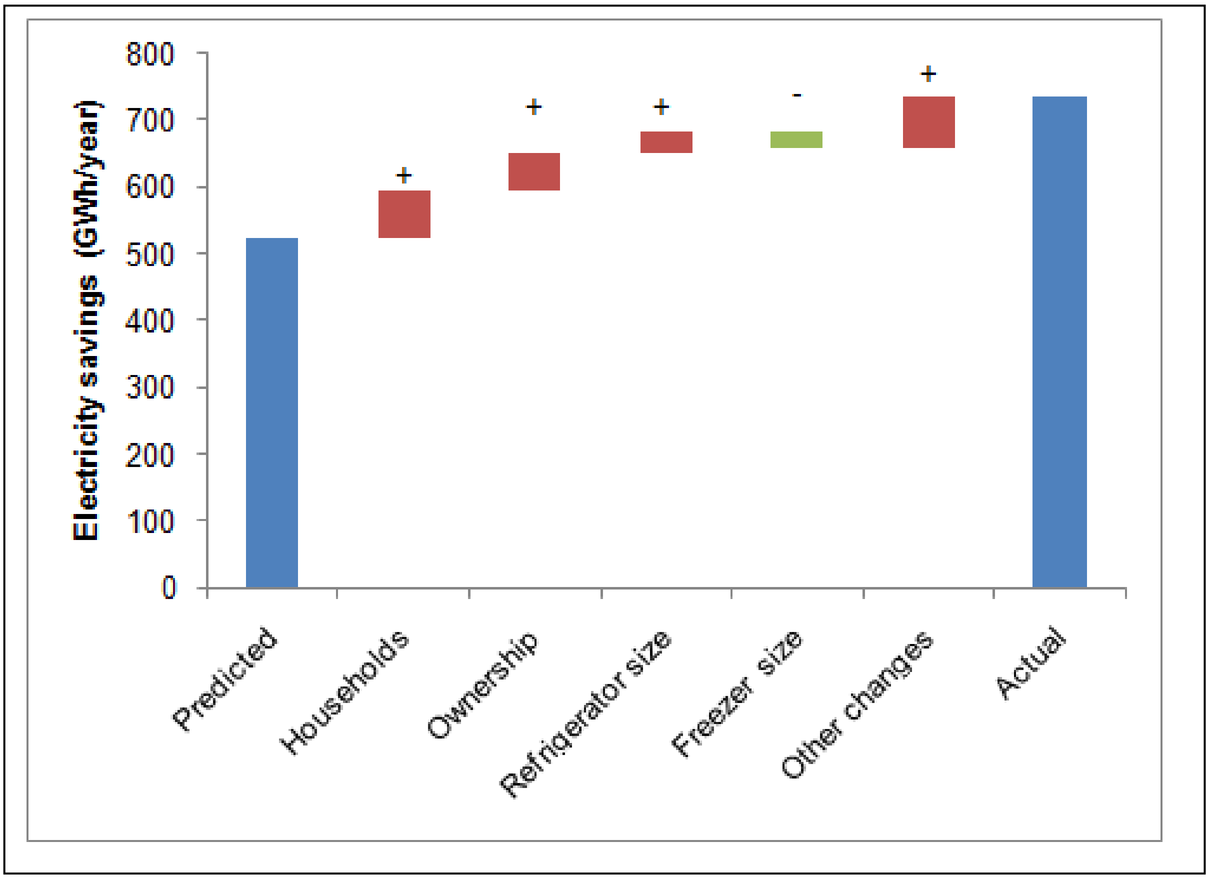


Figure 2: Decomposition of revised refrigerator electricity savings in 2010 (GWh/year) (due to MEPS-2005

Thus, the savings from these regulatory measures are more than expected (as estimated in 2000 for the ex-ante regulatory impact assessment).

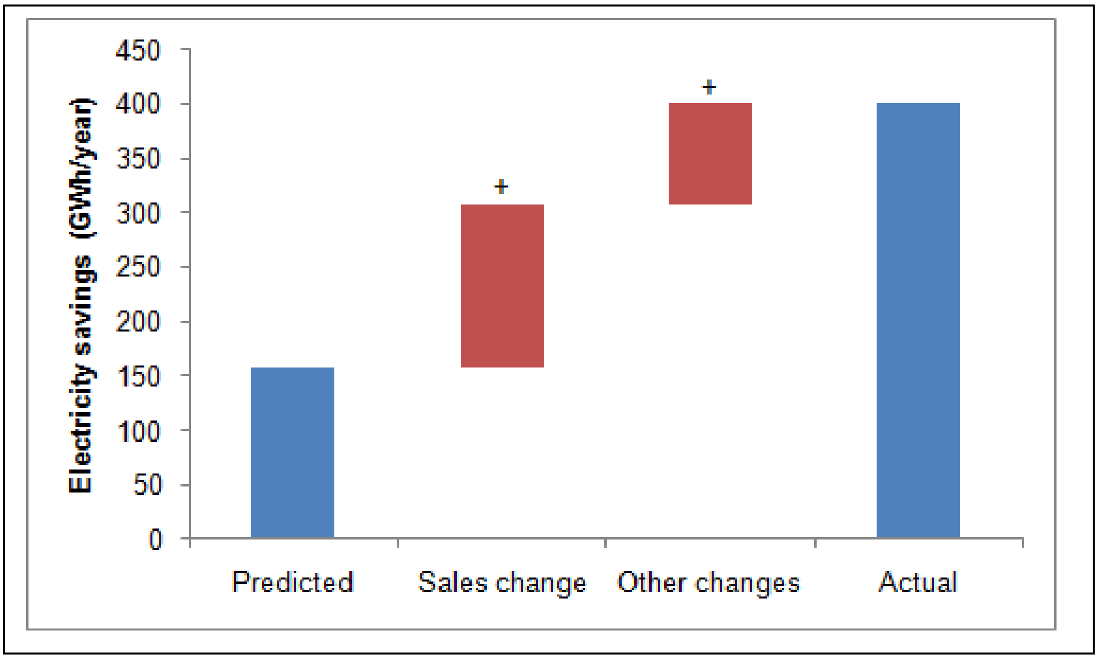
Air condition impacts

Similar findings are observed for recent policy measures for residential air conditioners [2]. The results of the study show that the introduction of MEPS:

- Improved product efficiency and reduced energy consumption, compared to what would have occurred without the regulations. The annual rate of improvement before MEPS was around 0.5% (mainly driven by energy labelling alone), but grew to around 3% after the 2004 MEPS and to around 4% after the 2006/07 MEPS.
- This resulted in an estimated cumulative energy saving to 2008 of 515 GWh, which represents a cost savings of AU$88.9 million based on 2009 Australian average electricity tariffs. In total from 2003 to 2020, the combined cumulative energy savings due to MEPS 2004 and MEPS 2006/07 was estimated to be 6.5 TWh, worth approximately AU$1.13 billion.
- Did not generally affect the price of air conditioners. However, it is possible that the 2006/07 MEPS slowed the rate of decline in air conditioner prices, but other market trends may equally have been the cause of changes in price trends over 2005-2008.
- Did not affect the number of models available in the marketplace and hence did not appear to affect consumer choice.

The evaluation findings were compared to the forecast impacts made for the 2003 Regulatory Impact Statement (RIS) and the 2005 RIS, with the following results:

- Based on data available to 2008 the actual annual energy savings impacts are 65% above the combined forecasts of the 2003 and 2005 RIS.
- The current estimate of the total actual impacts till 2020 is 195% above the projected impacts



of the 2003 and 2005 RIS.

Figure 3: Decomposition of revised air conditioner electricity savings in 2010 (GWh/year) (due to MEPS-2004 and MEPS-2006

These large differences in the forecast impacts versus those found in this evaluation are primarily due to the 2003 RIS forecasts being based on a smaller forecast of sales volume than actually occurred. Actual sales of air conditioners were 108% higher from 2002 to 2008 than anticipated by the 2003 RIS. This occurred because there was a large increase in air conditioner ownership from 2000 to 2010, despite only small changes in ownership through the 1990s (so was difficult to foresee). This may in part be driven by the rapid decline in purchase prices during this period due to the increased dominance of China in the world air conditioner market. The rapid per unit price decreases that occurred over the past decade are expected to slow beyond 2010.

Other factors that caused differences between forecast and actual benefits of MEPS are the result of the RIS methodology used to determine the efficiency gains, changes in the product mix being sold, and the accepted need to be conservative when forecasting efficiency gains for RIS.

Generic findings

From these two detailed evaluation studies, it is possible to suggest some generic conclusions, about standards and labelling:

- These are very effective energy and carbon emission mitigation policy measures;
- They reduce household energy bills significantly;
- They do not reduce consumer choice of products on the market;
- Little or no significant increase in purchase price, and certainly no higher than a total lifecycle (purchase plus running costs) within the limits of available technologies in a competitive market;
- Thus, they can be very cost-effective carbon mitigation policy measures (they often have negative societal cost);
- Ex-ante appraisals tend to underestimate energy savings, but it is natural to be conservative where there are significant future uncertainties and to some extent it is wise not to routinely

overstate the potential future benefits (there would be justifiable criticism if future savings estimates were always overblown);

- With a set of conservative assumptions, findings of a benefit cost ratio of greater than 1.0 will almost always be better in practice;
- This suggests that where conservative future assumptions are routinely adopted, more stringent regulatory proposals that are closer to a benefit cost ratio of 1.0 may be justified.

Approach to long-term evaluation of energy savings

Undertaking such a long-term evaluation analysis is not trivial: the approach used was to develop bottom-up stock models with sales data (matched with energy attributes) over the entire period since the policy measures were introduced, then develop counterfactual scenarios to attribute the impact of each individual policy measure as it was introduced. Changes in actual size, features and product type were taken into account to provide updated (ex-post) estimates of energy savings.

The approach taken to estimate the ex-post energy savings is based on using the same end-use models used for ex-ante appraisal of policy measures (ie before the measure is implemented and used to develop a regulatory impact assessment). The model is then updated to include all known (actual) changes to all the input variables, plus revised projections based on later knowledge. The latest efficiency data are used to generate a trend line to 2009 illustrating what has happened in the past (to date), together with the latest ownership, sales share data (by group) and household estimates. Multiple historic efficiency scenarios are then run in order to estimate the influence of changes in energy policies on the earlier baselines for energy consumption. For some of these earlier scenarios it is of course difficult to know what would have happened if the policy measures were not introduced. These so called ‘counterfactual’ scenarios, which are done separately for all ten refrigerator groups, are the key to undertaking a good retrospective analysis or a re-appraisal of policy impact. An example of the efficiency scenarios undertaken are shown for Group 5T refrigerators.

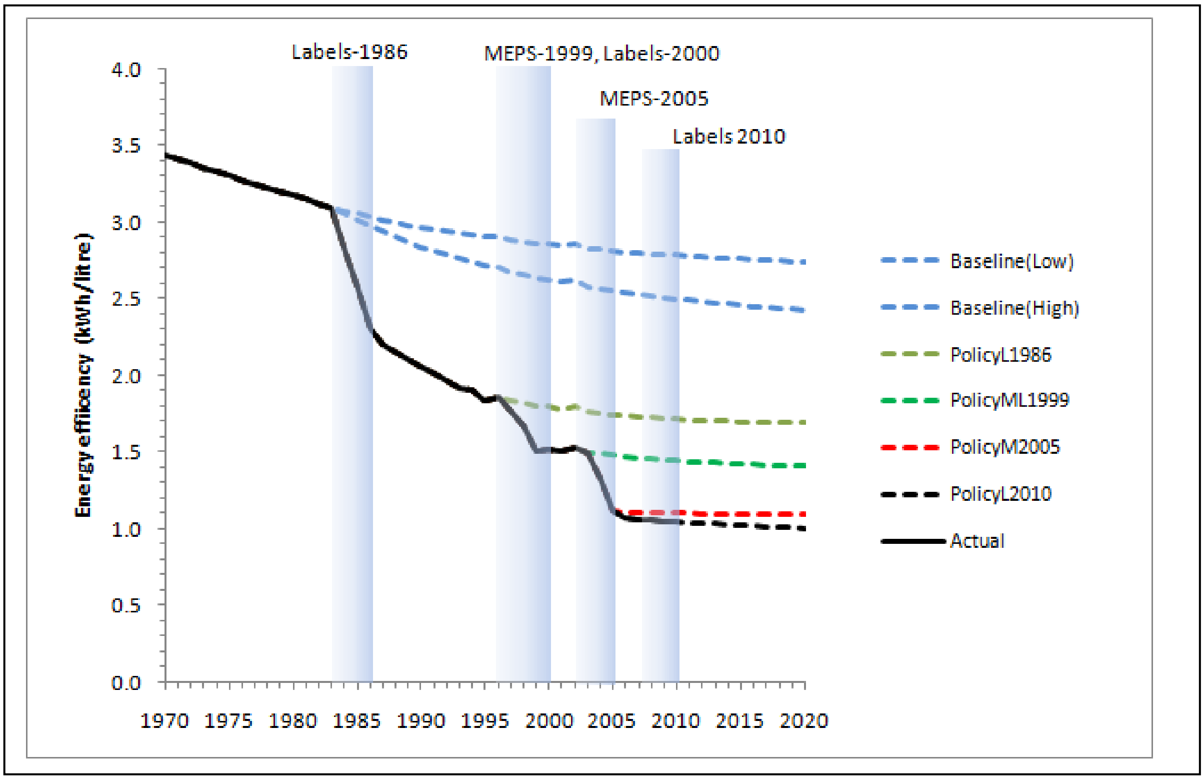


Figure 4: Changes in energy intensity (efficiency scenarios for refrigeration Group 5T)

The model is run for each scenario to estimate the historic energy savings to 2008, and a revision of the likely energy savings through to 2020. In Figure 4, the solid black line represents “reality” and has been accurately established through analysis of historical appliance sales data year by year. The dotted policy lines are the projected energy trends in the absence of subsequent energy programs. The savings ‘attributed’ to each program measure is proportional to the area between each of the program lines. The total energy savings are well known as the lower boundary (actual = black) is based on the actual energy consumption of all products through detailed market analysis. Estimating the energy trend line in the absence of each policy measure has some uncertainty associated with it, as there is no reality against which to check the results. But sophisticated techniques to track trends over time make these judgements relatively objective in this type of analysis as set out in the following section.

Projecting scenarios

This is the most difficult part, as it is difficult to make historic projections because analysts will never know what would have happened in the absence of the policy measures being evaluated (sometimes referred to as the counterfactual).

For the first baseline, prior to any policy measures, it is likely that some efficiency improvement would have occurred. This 'autonomous' rate of improvement is unknown and can be included in several ways:

- No improvement in efficiency,
- Fixed efficiency improvement (eg 1% per annum),
- Changing efficiency improvement (eg 1%, then reducing each year after)
- Simple extrapolation of the last two data points,
- Extrapolation based of several previous data points.
- Efficiency improvement determined by analyst, eg a declining autonomous rate, and different for each appliance group

The same decision needs to be made for subsequent policy scenarios. For the refrigeration appliances a fixed efficiency improvement was chosen, which then declined over time. The earlier scenarios have a higher rate of improvement since it is likely that it is easier (cheaper) to make efficiency improvements on less efficient appliances.

For later scenarios, the same issue applies, though it is likely that there will be less increase in autonomous efficiency (without further program measures). By examining the data it appears that the efficiency/consumption almost levels off following the introduction of more stringent refrigeration product policy measures, which is expected. This is especially noticeable for the case of refrigerator MEPS in 2005, which required an average decrease of 40% in energy in the few years prior to its introduction – almost all models had to be re-designed and re-engineered to meet the new standards, so naturally there were fewer routine opportunities for incremental design changes in most products in the following years.

For the air conditioner scenarios a fixed annual percentage improvement based on the latest two available points was chosen (since the fewer data points, and significantly larger improvements were realised). The underlying efficiency trends used as a baseline prior to MEPS were reasonably well established as a result of energy labelling, which was introduced in 1987 [10].

Correcting 'size' effect on efficiency/intensity

When the efficiency indicator being evaluated does not match the true efficiency metric, then some correction may be needed. In the case of refrigerators, the average ambient temperature is the key driver for energy consumption during normal use. The energy value on the energy label is determined at a single elevated temperature, so adjustments are generally required in different climatic regions. The issue of user related energy consumption elements is not well addressed in any of the major refrigerator test procedures, so making adjustments for these factors is not currently possible.

In the case of air conditioners, the market has been historically made up of single speed compressors, which tend to have only small changes in average efficiency under different cooling outputs, as varying the output is achieved by cycling the compressor (each cycle is effectively operating at full capacity when on – only the frequency and duration of cycles changes in response to load output). Air conditioner efficiency is also affected by changes in external and indoor conditions, although these changes can be estimated to some extent through standard refrigeration system modelling approaches. Over the past five years the market share of inverter driven products has dramatically increased, to the point where they make up 80% of residential sales. These products can improve their efficiency significantly at part load, so the actual operating conditions can affect the average efficiency. Incorporating these effects requires significant adjustment at an individual model level, where part load data are available.

Where possible, corrections for these types of effects need to be introduced into any evaluation analysis (ex-ante or ex-post), as consumer benefits need to be based on actual energy consumption (and the associated actual energy savings) rather than be based on the energy consumption changes expected under laboratory conditions alone.

Terminology

During the course of the two studies, a consistent set of terminology was used.

Table 1: Terminology

Term	Meaning
Counterfactual	Often used in evaluation studies, the two studies avoided using this term, to avoid confusion
Ex-ante	Beforehand – projections using estimates of future values
Ex-post	Afterwards – examination of historical data to establish actual trends
Formative evaluation	Evaluation of a policy process
Summative evaluation	Evaluation of the outcomes and impacts (the main focus of the evaluation reports)

In addition, the two projects developed the following naming convention for the different scenarios.

Table 2: Scenario naming convention

Scenario label	Interpretation
Baseline	Scenario prior to any policy (to be evaluated) implementation. Multiple Baseline scenarios could be developed (high and low) to capture a greater 'autonomous rate of improvement'. Any projections are shown as dashed lines.
Policy*XYEAR*	This includes actual data to the intervention year, all policy up to and including the year in the label. The projections for this scenario beyond the implementation year do not include any further policy measures and are shown in charts as dashed lines.
Actual	Are the measured data (or processed from measured data), included as a solid line in charts.

So, for example, for refrigeration the following historic efficiency scenarios have been developed (for each of the 10 refrigeration groups):

- Baseline (Low) – small increase in efficiency after 1983, following the earlier rate of efficiency improvement, then levelling off;
- Baseline (High) – Similar to Baseline (Low) but a higher rate of efficiency improvement after 1983;
- PolicyL1986– to reflect the consumption due to 1986 labels, but no subsequent policy. The level of savings for this policy is the difference between this scenario and the Baseline (High) or Baseline (Low) scenario. This scenario also acts as the baseline for the following policy scenario;
- PolicyL2010 – includes all policy introduced to date, and expected impacts into the future from these, but assumes no further policy measures.

Approach to examination of price change, consumer choice

Purchase price

In order to assess whether MEPS had any significant price impact over time, the following parameters have been calculated for each group for each year from 1993 to 2008 (latest year of available data which is fully analysed):

- Average price in nominal dollars by year;
- Average price in 2008 dollars (corrected using the official Cost Price Index for 'all groups', which tracks relative price changes over time) by year;
- Total volume in adjusted litres;
- Average price per adjusted litre in nominal dollars by year;
- Average price in 2008 dollars per adjusted litre (corrected using CPI all groups) by year.

It is necessary to track volume (size) over time as changes towards smaller or larger sizes can impact on prices. Where volumes are changing within a group, price per adjusted litre of volume gives a better indication of price trends over time.

Consumer choice

A quantitative analysis of the energy labelling registration database and GfK market sales data was undertaken to assess the range of consumer choice as various regulatory changes were introduced over the period. For refrigeration appliances, the energy labelling registration database provided estimates of the number of (approved) models on offer on the market from 1987 through to 2010, whilst the (GfK) sales data gives an estimate of the models actively sold from 1993 through to 2009. A similar approach was used for air conditioners, though clearly fewer years of data were available, due to the shorter period of policy measures being in place.

Decomposition approach to revised appraisals/evaluation of energy savings

After undertaking an evaluation it is useful to cross check against any appraisals done beforehand. At its simplest level this means comparing the estimated energy savings. However a more sophisticated way is to examine all the input data used in the original (ex-ante) analysis and compare these and where possible re-run these with both the original as well as up-to-date data. To show the impact of the difference in these variables a decomposition approach was developed to explain where the original appraisal energy saving estimates was different to the current evaluation estimate (eg due to larger products, more sales). For refrigerators, it was possible to do this detailed analysis for the appraisal of the 2005 MEPS, done in 2000, since the underlying assumptions used in the appraisal modelling were still available. Thus, for example, the sizes used in the 2000 analysis are compared against updated figures used in the 2010 evaluation (Figure 5).

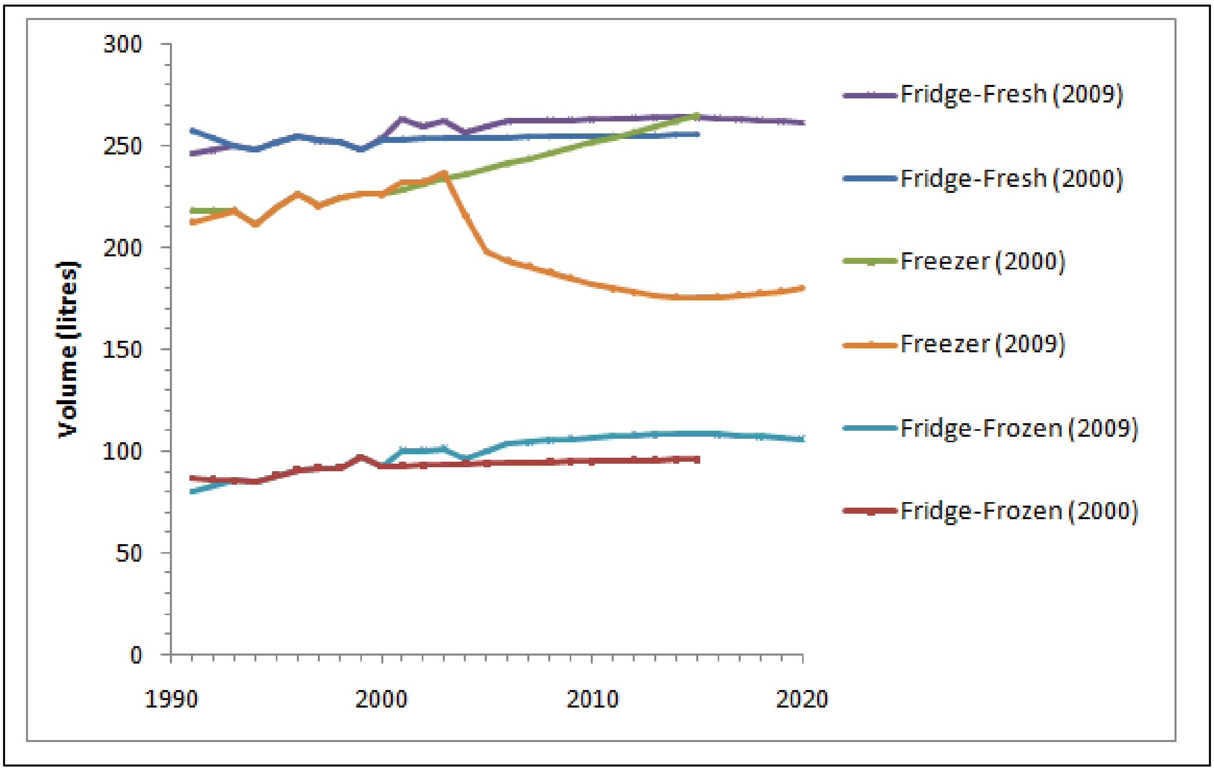


Figure 5: Change in the average size of refrigerators/freezers sold

Similarly it was possible to do this for the 2004 and 2006 AC MEPS. The results for both are given in the earlier main findings section.

Other findings/considerations

Some of the main findings have been discussed above; however, there are various other lessons to be learned, and a selection is listed below:

- To undertake such longs term evaluations, especially the decomposition analysis, requires detailed data on the original ex-ante assessments. It is essential that the underlying models and assumptions are retained for future analysts.
- Standard guidelines for such evaluations are important to allow synthesis analyses to be undertaken.
- No impact of the load profile was undertaken. Though difficult, this would be really useful, especially for more products which significantly affect peak loads, such as air conditioners.

Summary

Both studies showed that significant energy savings and carbon emissions reductions have already been achieved through energy programmes and that the savings actually achieved were larger than the original ex-ante estimates had suggested. The savings will also continue to accrue into the future. These savings were achieved with little or no observable impact on the average purchase price, whilst the number of models on the market has not been affected (in fact the number of available models increased with increasing levels of regulations).

This paper has also shown that it is possible to successfully undertake long term evaluations of product policy, and the experience in Australia provides some valuable 'lessons learned'.

Acknowledgements

The authors would like to thank the Australian Department of Climate Change and Energy Efficiency for the funding of the original research, and the peer reviewers for their comments on the first draft of this paper.

References

[1] DCCEE (2010a) Evaluation of Energy Efficiency Policy Measures for Household Air Conditioners in Australia (Report 2010/12). Prepared by Ryan *et al*, EnergyConsult. Available from www.energyrating.gov.au in the electronic library.

[2] DCCEE (2010b) Evaluation of Energy Efficiency Policy Measures for Household Refrigeration in Australia: An Assessment of Energy Savings Since 1986 (Report 2010/10). Prepared by Lane and Harrington, Energy Efficient Strategies. Available from www.energyrating.gov.au in the electronic library.

[3] Ellis, M; Jollands, N; Harrington, L and Meier, A (2007) Do energy efficient appliances cost more? Proceedings of the European Council for an energy efficient economy, June 2007.

[4] Dale L; Antinori, C; McNeil, M, McMahon, JE; Fujita, KS (2009) Retrospective evaluation of appliance price trends, Energy Policy 37: 597-605

[5] Gillingham, K; Newell, RG; Palmer, K (2004) Retrospective Examination of Demand-Side Energy Efficiency Policies. Resources for the Future, Washington DC

[6] Schiellerup, P (2002) An examination of the effectiveness of the EU minimum standard on cold appliances: the British case. Energy Policy 30, 327-332

[7] Weiss, M; Junginger, M; Patel, MK; Blok, K (2010a) A review of experience curve analyses for energy demand technologies”. Technological Forecasting & Social Change 77: 411–428

[8] Weiss, M; Patel, MK; Junginger M; Blok, K (2010b) Analysing price and efficiency dynamics of large appliances with the experience curve approach”. Energy Policy 38: 770-783

[9] Energy Efficient Strategies (2008) Consultation Regulatory Impact Statement of proposed revisions to the method of test and energy labelling algorithms for household refrigerators and freezers. E3 Report no. 2008/04. June 2008. Available from www.energyrating.gov.au in the electronic library.

[10] Energy Efficient Strategies (2008) Regulatory Impact Statement: Consultative Draft: Revision to the Energy Labelling Algorithms and Revised MEPS levels and Other Requirements for Air Conditioner.

Residential demand in France: evolution and opportunities

Mihai Petcu, Senior Consultant

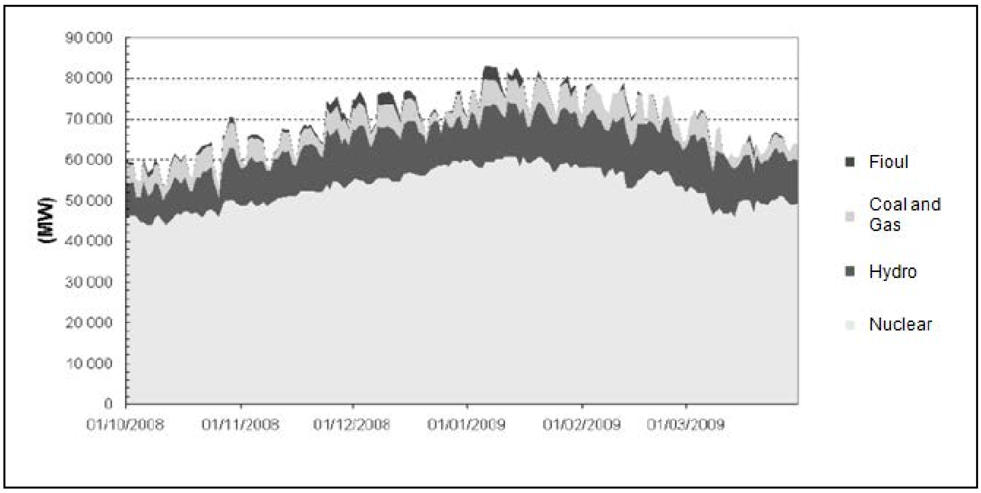
BASIC Consultants

Abstract

The French Residential Demand Response market is unique in Europe, and the world, due to a host of factors ranging from the mostly nuclear energy mix to the strong use of electric heating in most dwellings. The majority of important entities in the field of demand response conclude that the French market has huge potential for residential demand response programs, yet this potential is difficult to quantify and largely untapped even though France is the only country where an independent residential aggregator is present. Legacy demand response programs, largely based on industrial load shedding and interruptible tariffs, are slowly evolving towards more complex models of consumer participation. Residential participation is increasing, yet its full potential is as of yet largely unknown. The current paper aims to paint a clear picture of this residential consumption landscape in France by quantifying its potential and the underlying opportunities for demand response. The situation is analyzed in the specific context of the French market, its accelerators and strong barriers. This paper concludes that residential demand participation is weak due to a number of factors ranging from badly adapted market mechanisms to poor regulation presenting slow prospects for evolution.

The French situation

The French energy mix is characterized by a heavy reliance on nuclear generation, with more than 80% of the country’s electricity coming from this source. This obviously creates a solid base of non-flexible generation, although some experiments have been carried out in order to test the responsive capabilities of nuclear loads. Hydro is the second biggest contributor and is generally used for reserve and balancing capabilities (hydro reservoirs in France have large capacities). Coal and gas come in during winter time, France being a winter peaking market, and fuel oil plants are also used during this season to balance out the demand peaks.



Production mix evolution for a series of winter days, 2008/2009, RTE

A competitive energy mix

The French energy mix is one of the most competitive in Europe in terms of electricity prices and CO_2 emissions. In this context, implementing Demand Response does not appear to be a priority for French regulators. Yet, harsher winters creating considerable peaks, threatening the stability of the network and brutally increasing wholesale prices have repositioned the importance of consumer participation for the future of the French network.

During winter peaks, the flexible capacity required to balance the network comes almost exclusively from fuel oil, coal and gas plants. The combination between the cost of operating these plants and the environmental impacts associated with their emissions is starting to bring forth a valid business case for the proliferation of demand response. More importantly, despite managing a network that is considered stable on the whole, the national Transmission System Operator (RTE) has witnessed some transmission difficulties on a regional basis. This is particularly the case in Brittany where investment in infrastructure has been stalling in comparison to other parts of the country. There is growing belief that demand-side measures present answers to the most serious of France's energy constraints.

Legacy demand response programs

At first glance, residential electricity consumption paints a very favourable picture for demand response. Electric heating is used heavily at national level and installations are still on the increase – two thirds of the heating equipment installed in new or renovated buildings is electric, although this trend will most likely be discontinued by new regulation governing energy consumption in buildings that is mostly unfavourable towards electric heating.

Legacy demand response programs have been tapping into this important potential for more than 30 years. Interruptible contracts for large loads and "dynamic rates" for both industrial and residential consumers introduced into the market in the 60's are still seeing a good following.

On-peak / off-peak pricing

On-peak/off-peak pricing has been flattening the demand curve ever since it took off in 1965. The tariff is usually offered in conjunction with a communication relay installed in order to control the operating cycle of accumulation water heaters (these are very common in France). Taken up by about one third of French households, the use of the tariff currently equates to about 20TWh of electricity storage.

The signals to the relay are sent by a DSO via PLC..

EJP – Effacement jour de pointe

The EJP – literally "Reduction during peak days", was launched in 1994 and was aimed at both residential and commercial clients. Based on a Critical Peak Pricing model, the tariff involves 22 days of high rates per year with the rates being obviously lower than the regulated retail rate for the rest of the year. The tariff has been a resounding success for industrial clients, who usually acquire emergency generation to deal with peak days (the program is so rewarding for industrial clients that it pays off the investment in the emergency diesel generators in about one and a half years), but less so for residential clients, who find the program particularly difficult to live with during peak days, where the price of the electricity is very high throughout the day (and not just for a few hours as is typical in other CPP-type tariffs).

The EJP is no longer available for subscription, but current contracts are still being honoured.

The Tempo tariff

The Tempo tariff is a TOU type tariff, where a three-tier rate structure is used. Three periods are defined: the consumers pay discounted prices during "blue days" (with each day seeing two periods – on-peak and off-peak), but see increased tariffs during white and red days, the latter presenting very punitive tariffs (about 4 times more than the regular rate). The customer receives a message, one day in advance, informing him of the next day's colour and thus rate. The tariff, rolled out by EDF has seen some success during the last few years, as more and more people have been turning to simple automation solutions to manage the changes in their tariffs.

Comparison between the three available types of dynamic tariffs

Tariff	Number of clients	Impact
HP/HC (Off-peak, on-peak)	11,000,000 Mostly residential	Equivalent to 20TWh of storage
EJP	700,000	6 GW in 2000 2 GW in 2008
TEMPO	1.2% residential 3.4% commercial 500,000 clients	300 MW "Red Days" 150 MW "White Days"

The deployment of the "Linky" smart meter and its limited DR functionalities

Smart metering is being massively deployed in several European countries yet these deployments are not following a single "European" direction. The Italian or Swedish models (more than 90% of Italian and all Swedish consumers are already fitted with a smart meter) are not being adopted in other countries – France, Germany, the UK, and Denmark are all following individual paths towards full deployment.

The deployment of smart metering in France is expected to start in 2012. The main goal of the installation of the Linky smart meter is to increase consumer participation. Its functionalities however will only support this goal to a certain extent. Deployed by the DSO (the national DSO is ERDF, its role in certain municipalities is taken over by smaller, local DSOs), the Linky will register consumption every 30 minutes, with the consumption data being communicated once per day via PLC. The limited capacity of 2400 bauds is the first indication that the meter will not be particularly DR friendly. Some remote operations are however possible --remote disconnection of a customer being a good example--and dynamic tariffs are implementable.

All in all, the Linky will not feature any meaningful Demand Response capabilities, although it may to some extent facilitate implementation of DR programs, by communicating consumption and tariff data via the in-built USB port. This data can be used by a home gateway to reduce different charges and respond automatically to evolutions in the price of electricity.

On the matter of DR functionality integration within the smart meter, the position of the national regulator is fairly clear: the cost of the integration of certain functionalities that will be used by some consumers should not be supported by all of them. That is to say that the integration of DR functionalities into the Linky would only be useful to certain consumers and that the cost of this operation should not be supported by all citizens (the Linky deployment is publicly funded).

Regulation and the market model

The regulation governing the demand response market in France has been slowly evolving over the last few years. The entry of the American curtailment service provider's business model onto the European markets and the growing interest for consumer participation, shown in particular by RTE (the French TSO), have encouraged the national regulator to put together a framework for a series of potential demand response services for the French market. Currently, demand resources can only participate in the market for "energy" type services, but the creation of new ways of integrating demand participation to balance the networks is under development.

The current participation model – an "energy" type service

The French market does not have a capacity market for resources to participate in. Instead, in order to allow some demand participation in the network balancing process, the CRE has developed a framework largely resembling the "energy" type service frequently encountered on the American wholesale markets like PJM or New England ISO.

The American DR energy service

The American DR energy service model involves voluntary participation of resources that react according to the price of electricity: when the price is high enough, resources will reduce consumption. There is no operator involvement, nor any emergency signals sent to the consumers, the latter choosing to reduce consumption exclusively due to the price of the electricity on the market. The service can be "day-ahead", with the consumer reacting to the location marginal price[1] for the next day, or "real time".

In the case of the day-ahead participation, the resources receive a payment based on the day-ahead LMP of which the transmission and generation components are partially or fully subtracted. Should the resource choose to participate in real time, it must first define a "strike price" at which a reduction of consumption is economically viable. Whenever the strike price is attained, the resource, generally through an aggregator, reduces the loads and receives remuneration on the basis of the real time LMP, of which again the transmission and generation elements (normally referred to as G) are partially or fully subtracted. In both cases, resource participation is voluntary and does not result from an emergency signal of some sort issued by the TSO.

The matter of the payment provided to resources participating in an energy type market has been under scrutiny for some time. Most market operators, such as PJM, New England ISO or the NY ISO, remunerate this type of participation on an "LMP – G" basis. The Federal Energy Regulation Committee has advised that this payment structure is to be modified, and that the full LMP is to be paid to demand resources, mostly in a bid to encourage demand participation.[2] It is thus expected that market operators will switch to full LMP remunerations.

The discussion on the remuneration of the participation of demand resources in an energy type service is also ongoing in France.

The French adaptation of the American energy service model

Demand resources in France can only participate in an energy type service and generally do so through demand response aggregators (apart from large industrial clients). The aggregators define a capacity and a price per MWh at which they can supply this capacity to the French TSO, RTE. When conducting their offer, the aggregators are unaware of the current price of electricity on the market as this price is not available to participants.

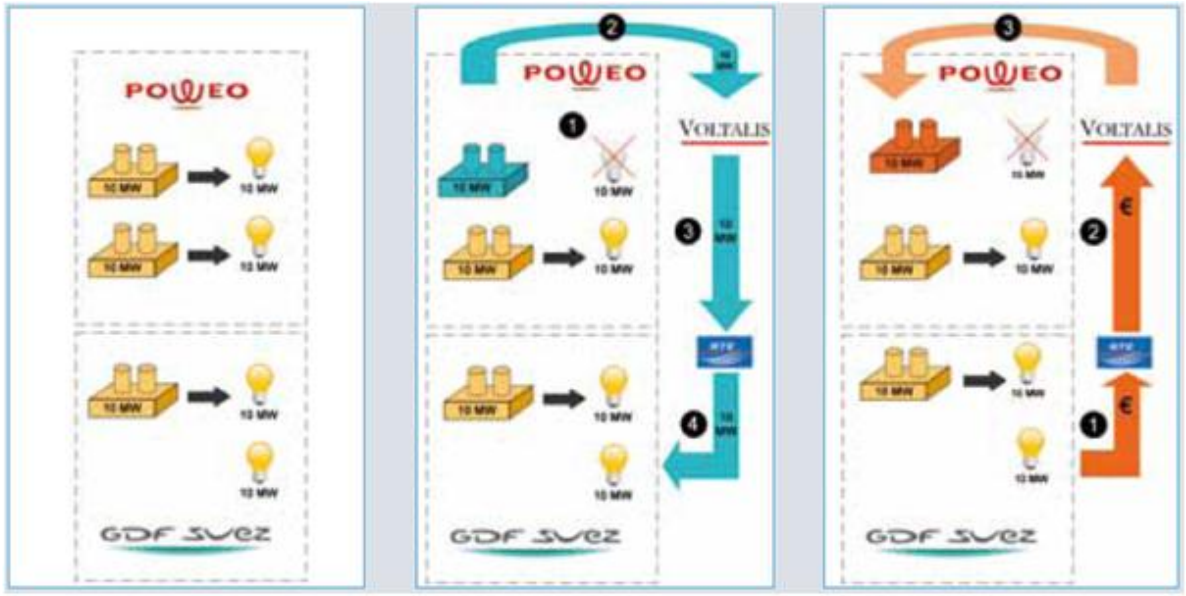
RTE does not discriminate between an aggregator's demand reduction bid and a generator's production bid, selecting the best offer on the basis of its price. If the aggregator's bid is accepted, the latter must provide the reduction in consumption or face serious penalties. If the aggregator has supplied this reduction, it is remunerated on the basis of its bid.

In June 2009, the French Energy Regulation Committee (the CRE) published a deliberation on what it considers to be a financial imbalance issue in the demand resource remuneration model. Before this date, the aggregators' bidding reductions with RTE received the full price of their bid. In a discussion that is similar to that which is currently being carried out in the United States, the CRE stated in its deliberation, that aggregators should pay the suppliers for the reduced consumption at retail rate.

---

[1] The location marginal price, or LMP, is the price that generators receive in a given transmission area (thus the location element).

[2] See FERC deliberation of the March 18th, 2010, "Demand Response Compensation in Organized Wholesale Markets"



1. The causes of the imbalance 2. The physical flows 3. The financial flows

Excerpts of the CRE's deliberation of June 9th 2009 Source: Décryptages, number 16, September / October 2009, BASIC adaptation

The figure above was used by the CRE to explain its deliberation. It roughly describes the procedure followed in the situation of a contingency event. The example presents two retailers, GDF Suez and Poweo, each with 20 MW of demand to cater to. A 10 MW imbalance is caused by GDF Suez's incapacity to supply its full 20 MW. RTE calls upon Voltalis (as a demand response aggregator) to provide 10 MW of curtailment in order to balance the grid. In this example, when providing the 10 MW, Voltalis curtails Poweo customers. In the French national regulator's view, Poweo is not remunerated for the full 20 MW it supplied, which is why it asks Voltalis to pay Poweo the retail price of the 10 MW curtailed.The discussion is essentially the payment of full LMP versus LMP-G. Voltalis obviously contests the decision.

The manner in which the CRE has chosen to exemplify its deliberation has several flaws as noticed by a number of observers, both in France and abroad. Yet, by using other market mechanisms, it essentially states that demand response aggregators should not be paid the full location marginal price and should only receive LMP-G (the price discounted of the retail price of the curtailed energy). Economically, the conclusion itself makes sense, but one can argue that the phrasing of the deliberation and the way in which it is explained certainly adds to the climate of ambiguity already surrounding the field. In addition, the lower remuneration will certainly deter potential demand response aggregators from entering onto the French market, particularly onto the residential one. This goes against the mission of the CRE to improve conditions and more generally pave the way for the smart grid in France. In a recent development, Voltalis won a legal battle against the CRE, when, on 3 May 2011, the French Conseil d'Etat (State Council) annulled the National Regulator's deliberation.

The capacity model – a model for the future

For the moment, the French regulators have not opened the way for a capacity service. Considered by many actors in the demand response scene as one of the key factors for the development of a DR market, the capacity service is only now beginning to gather some momentum in France. A series of regulatory reforms discussed in Parliament have already asked for the creation of a true capacity market – the Nome law in particular is a good example. The market will most likely be modeled on the capacity services found in the USA.

The capacity model

The capacity model involves an engagement that a demand resource takes to provide a certain reduction in load, whenever required by the TSO. The service is thus an agreement of availability to curtail from the resource. The operator remunerates this availability on a daily basis, in the exact same manner that an emergency generator is remunerated for keeping a plant on stand-by.

The necessary capacity is generally defined by the TSO. Capacity auctions are then organized, in which resources bid a certain volume at a certain price. Once this volume clears in the auction, the resource is required to have the capacity available at all times, upon receipt of an emergency signal.

The capacity model for the French market

According to the French Energy Regulation Commission it is highly unlikely for a proper implementation of the capacity market model to be seen in France before 2016. Despite the Nome report and other similar legal discussions, the general feeling is that the CRE has not made a priority out of creating a capacity market in France.

When this capacity market will come to be is not certain. What is certain is the fact that it will be based on the American model and that its ultimate purpose will be to incentivize consumer participation on the long term, by remunerating resources for their availability to curtail.

Ancillary services

Ancillary services include regulation, synchronized and non-synchronized reserve. The intervention of the FERC and the desire to integrate consumer participation at all levels of the supply-demand equilibrium has led to the creation of new services for demand reduction valuation.

Regulation

Regulation services involve the provision of rapid, emergency power in order to correct modifications in frequency. Historically achieved through interruptible contracts, the frequency regulation service has been recently opened to demand response in the US. Technically difficult – when a regulation event is triggered a resource needs to reduce load in less than 5 seconds – this service also remunerates considerably. However, it is difficult to envision DR participation in the regulation service in France.

Reserve

The notion of demand response for reserve implies substituting the power obtained traditionally from both increasing the output of operational plants (in the case of synchronized reserve) and activating stand-by emergency generation (in the case of non-synchronized reserve) with reductions in demand. Since reserve events can happen at all times, resources receive payments for availability in a manner that is similar to the capacity model. Performance payments are also granted every time participation is achieved.

Well developed in the USA and the UK, DR reserve services are only now starting to take off in France. RTE has launched a wide-scale project aimed at providing palpable elements of the potential use of demand response for reserve requirements. The project is ongoing, but it is expected that a rapid reserve service will be available on the French market before any kind of capacity market.

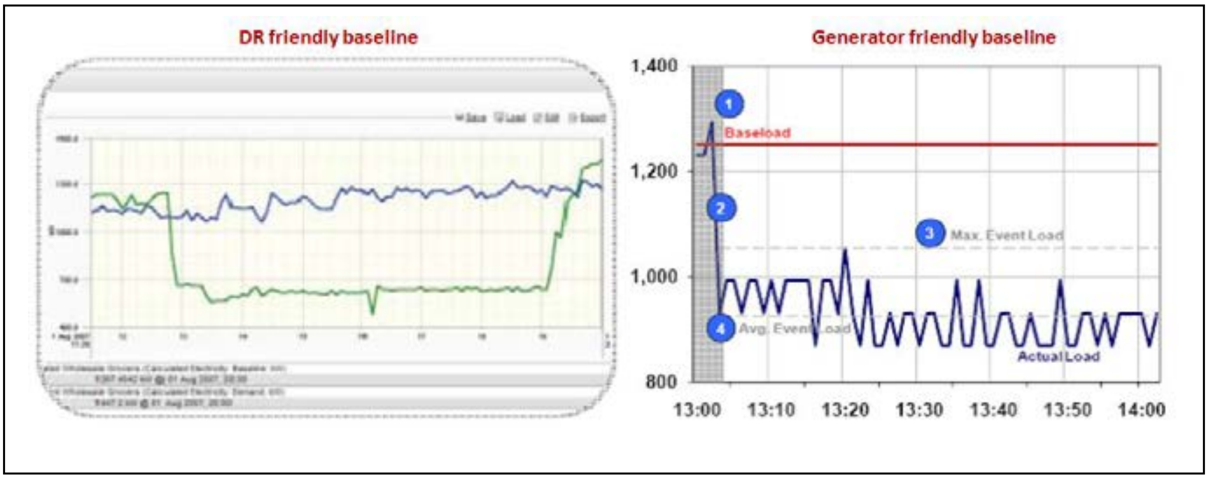
Measuring demand response

If there is more or less a consensus in terms of the way in which Demand Response is monetized, the same cannot be said about how DR is measured, the procedures differing from market to market, with some TSOs even providing several measurement mechanisms.[3] At the heart of the issue is one question, shared by all operators: What would the level of consumption of a given resource have been, had DR not been triggered, meaning what is that resource's baseline. The answer to this question can have a strong impact on the development of DR in a given country.

---

[3] See PJM Measurement & Verification document www.pjm.com

In most countries where the DR market is incipient, the baseline calculation is relatively simplistic and tends to be generator friendly. Where developed markets exist, complex mechanisms that use historic data to calculate a normal level of consumption in the absence of emergency situations are employed in order to determine a more DR friendly baseline.



A DR friendly baseline compared to a generator friendly baseline (French situation)

Source: EnerNOC

A baseline should satisfy three principles:

- Precision: the consumers should only receive credit for what they genuinely reduced
- Simplicity: the consumers should be able to understand the methodology employed for determining their baseline
- Integrity: the baseline should prevent fraud and determine irregular consumption

The baseline used for determining a demand resource's performance in France satisfies only one of these criteria: simplicity. This baseline is of a generator friendly design, which instigates to irregular consumption, free ridership[4] and does not precisely measure the value of reductions. For the moment, the baseline is a flat line of the value of the resource's consumption at the moment when the DR event is called by the TSO (see figure above right). There is thus a perception that the consumption of a demand resource is completely flat throughout the duration of a demand response event. This is rarely true.

The way the market model is constructed also works against the French model for baseline calculation as it invites "free ridership" or in other terms a remuneration for an apparent reduction in consumption, rather than a real one. For example resources know several hours in advance, say at time "t - 2 hours", that they will be subjected to a DR event at time "t", and they know that their DR performance will be calculated according to their consumption value at time "t". This effectively invites resources to ramp up consumption in the 2 hours between "t – 2 hours" and "t", thus creating themselves, through irregular consumption, a much more interesting baseline and a prospect for bigger revenue.

The only merit of the French baseline model is that it is simple for the resources to understand. Since the Energy Regulation Commission is already aware of this mechanism's flaws, one can expect change to intervene in the foreseeable future.

---

[4] Free ridership means obtaining demand response credit, without actually reducing consumption, but rather benefiting from the natural downward variations of the load. The opposite phenomenon can produce a situation where despite a reduction in load, resources are not remunerated due to the natural upward variation of the load, that when compared to a flat baseline shows an increase, not a reduction in consumption.

Demand Response service providers on the French market

Despite its numerous set-backs, the French market sees an active participation from Curtailment Service Providers, and is set to see even more involvement in the future. The French market is the only market in Europe that presents an independent, pure-player[5] aggregator, through Voltalis. Industrial and commercial aggregators exist, Energy Pool being their best known representative. This aggregator presence only goes to prove that there is still a lot of untapped potential on the market.

Voltalis – the pure player residential aggregator

Voltalis is the first pure player residential aggregator in Europe. The company obviously entered the French market in order to profit from the high penetration of electric heating (both space heating and water heating). To manage loads, the company uses simple GPRS interrupters connected directly at the electrical panel. This kind of equipment only allows Voltalis to fully shut down all connected heating equipment, making partial reductions impossible. For the end consumer, this usually means short 20-minute bouts where both space and water heaters are cut off.

Voltalis seems to incur fully installed equipment costs that are bigger than those seen by their American counterparts. This is due to the price of the equipment itself and the need to have it installed by a professional, bringing the end-cost to somewhere above €200.

The aggregator's client park is said to be expanding and comprises currently somewhere in the region of 12,000 residences. This puts the maximum capacity that Voltalis is able to supply to between 20 and 30 MW. An interesting feature of the company's business model is the fact that it does not remunerate its end clients for participating in the DR program. DR is sold to the consumers as a way to reduce their electricity bills.

Voltalis is having a difficult time on the market; it constantly contests CRE decisions concerning it and has purportedly not, for the moment, struck a profit.

Energy Pool – the successful industrial aggregator

Energy Pool is the biggest French aggregator, managing between 600 and 1000 MW of capacity. The company works exclusively with very large industrial and commercial clients (in the 10 MW range), and manages loads manually, without employing any automation.

The company provides their reductions in RTE's energy-like market and is studying entry onto the rapid reserve market project. The company has recently been acquired by Schneider Electric who will most likely use it as a platform to launch their smart DR – energy efficiency building packages to the European markets (the company is already working extensively in the US).

EDF – Edelia – a potential entrant that will change the DR landscape completely

EDF is the largest supplier of electricity in France, being only challenged slightly by Direct Energie and GDF Suez.[6] The company has an extensive client base which has already been habituated to DR initiatives through interruptible contracts for industrial clients and through dynamic tariffs for both industrial and residential consumers.

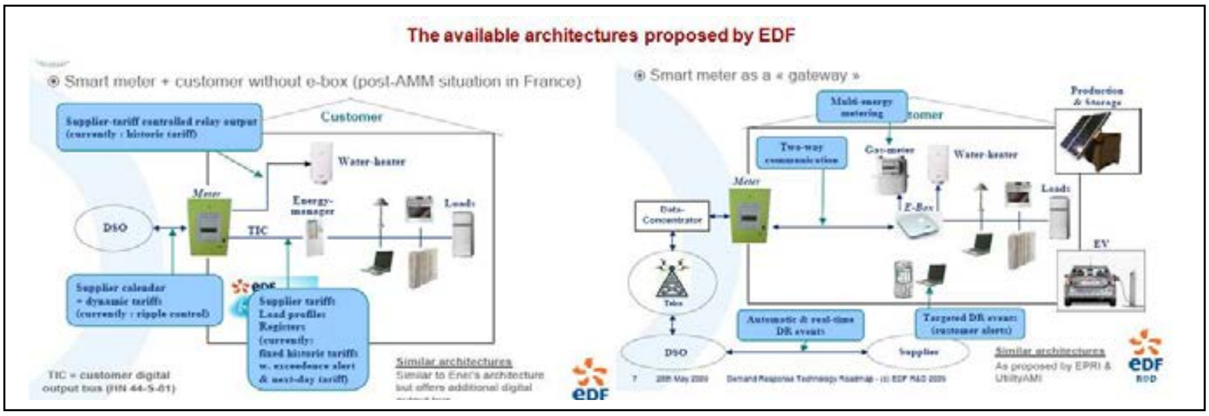
EDF's entry into the DR market is expected by a number of stakeholders, including the Energy Regulation Commission and RTE. The company has already created a subsidiary, Edelia, to deal exclusively with Demand Response. The EDF business model implies the use of home gateways, energy boxes or some sort of energy manager to curtail residential loads. The architecture of the final solution is yet to be decided, but it is clear that the gateway will connect to the Linky smart meter for some actions.

---

[5] Pure-player – fully independent, not attached to a retailer or DSO.

[6] Poweo, the electricity supplier, has recently announced their intention to leave the residential market

Through Edelia, EDF has already participated in the “Brittany Forward” DR program aimed at increasing consumer participation in the French region of Brittany. The company used an Energy Box (manufactured by Sagem) to control heating loads wirelessly. The Linky was not a part of the experimentation, but its role is presently being considered. It must be noted though, that EDF may face some legal scrutiny with regard to its access conditions for aggregators choosing to enter EDF’s



park.

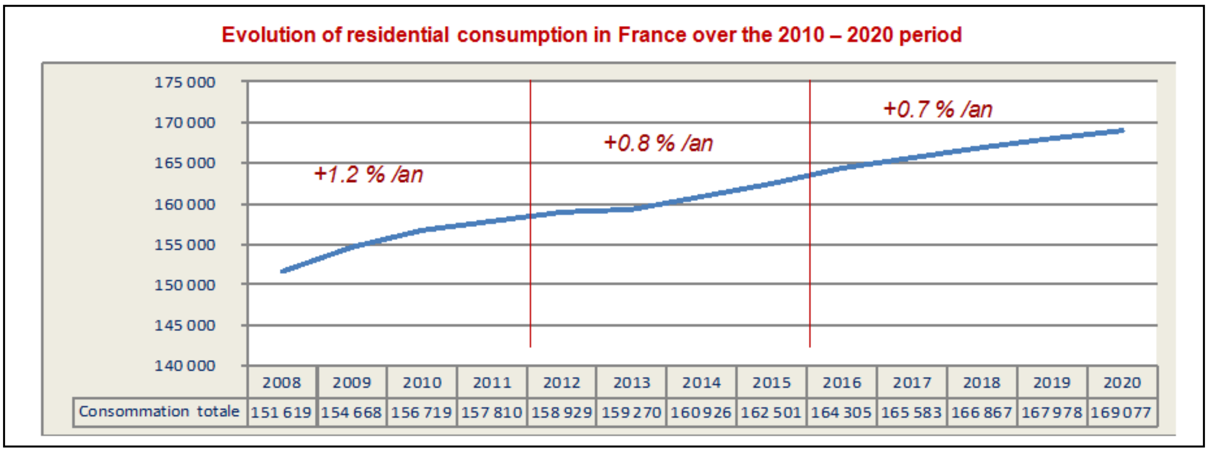
The proposed architecture of the EDF/EDELIA solutions

Source: EDF

Quantifying residential consumption and its potential for Demand Response

With high electricity usage determined mostly by easily controllable heating loads, the residential market in France promises interesting potentialities for Demand Response. Yet, apart from some figures regarding electric heating consumption, most of the potential is yet to be quantified. In order to clearly determine it, BASIC Consultants have developed a bottom-up consumption model aimed at providing a clear picture of residential demand in France by starting with individual level equipment and going up. The model is built over a 10-year period, starting from 2010. It shows the evolution of the consumption curves and the impact of demand response on the load curve.

All residential equipment fleets have been modeled on the 10-year period. The trends towards more energy efficient equipment have been integrated, as has the entry of the electric vehicle. The European REMODECE study has sourced some of the individual load curve profiles, while the others were developed from internal studies carried out by BASIC with different equipment manufacturers



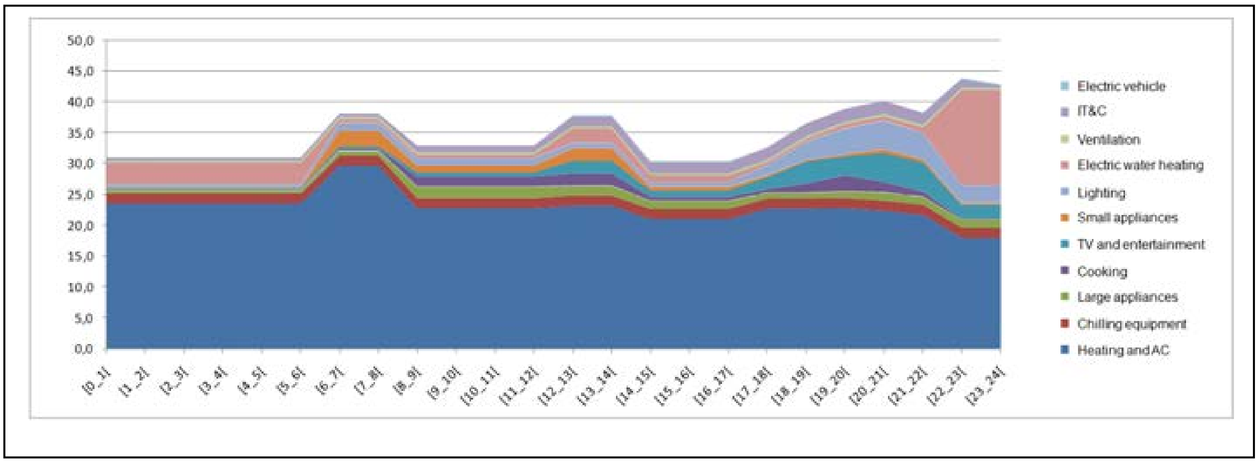
and certification organizations.

The evolution of residential consumption in France over the 2010-2020 period

Source: Basic

An increase in residential consumption

Residential consumption is expected go up in the following ten years in France, however the BASIC model seems to indicate that this consumption will be increasing at a lower rate than was previously described by other organizations, such as RTE for example, who has predicted an increase of roughly 3% per year. Basic's assumptions can be explained through the passage towards more energy efficient lighting solutions and through the substitution of a part of traditional electric heating equipment with more energy efficient heat pumps.



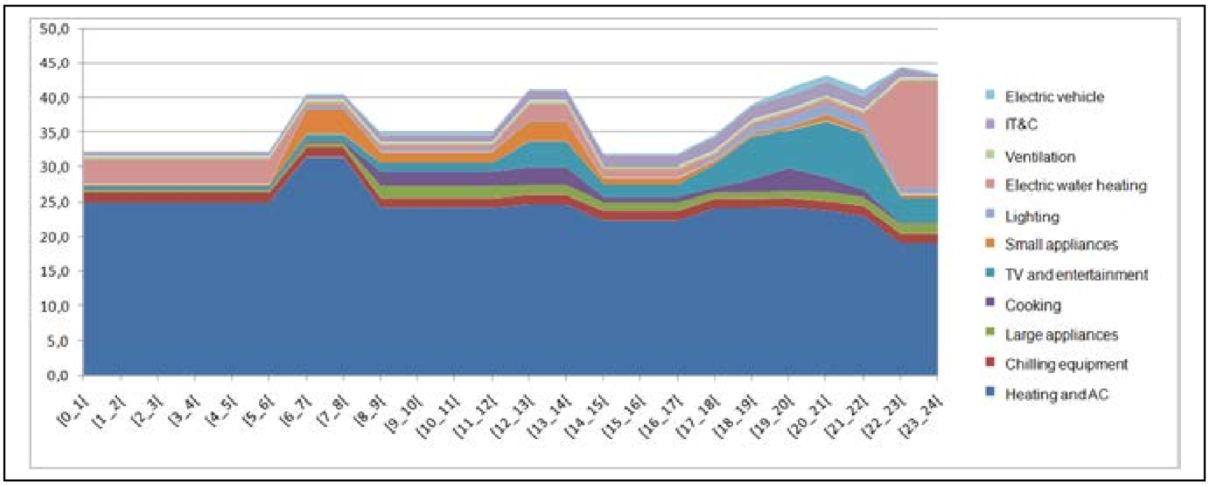
Residential consumption by equipment type, for a peak winter day, France 2010

Source: Basic

During a typical winter peak day in 2010, residential consumption reached a maximum level of about 45,000 MW, in the evening, which represents roughly half of all demand. The 7pm peak, which is quite notorious in France, appears to result from both residential and commercial consumption reaching high levels. The model also shows that residential consumption is in itself more regular than the total load curve showoff the French system as a whole (this load curve being far more irregular).

Electric space heating is by far the number one contributor to the national residential load. Water heating that starts after 10pm is a distant second, but this equipment is already managed via demand response relays. TVs and other electronics complement lighting to push up the 7pm peak.

The situation will obviously evolve as we reach 2020, with the load profile taking on a more pronounced peak, irregular shape. The peaks which are noticeable today will become more severe by 2020. The 7pm peak will become harsher, particularly due to the effects of consumer electronics such



as large flat screen TVs.

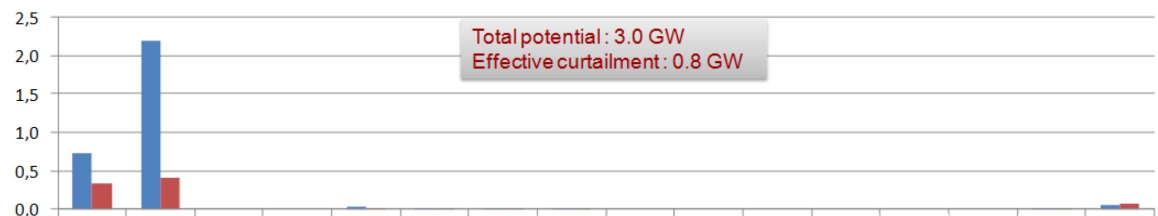
Residential consumption by equipment type, for a peak winter day, France 2020, Source: Basic

An important change is the expected decrease in the lighting load whose participation goes down heavily to less than half of its 2010 value. The electric vehicle will also start to have an impact, although this impact will only be in the region of 1GW should the EV not go through a DR program.

The associated potential for Demand Response

After achieving the construction of the residential load curve and tracking its evolution up to 2020, the model goes one step further in order to determine the associated potential for demand response by presenting a series of scenarios of effective curtailment. In order to evaluate these elements, the daily load curves are separated by the different types of equipment. The equipment is considered to be able to curtail if it has the ability to receive and respond to a curtailment signal, be it an emergency signal or a price signal.

The full potential of DR on the French market is roughly estimated to be at about 3.0 GW, by 2015, mostly coming from electric heating – both conventional and via a heat pump – with small EV participation. As the following graph shows, the potential associated to electric water heaters has not been considered. This is due to the fact that this equipment is already controlled remotely by the



	Heat pump	Heater	Other central heating	AC	Cooling	Clothes dryer	Washing machine	Dish washer	Cooking	Electro nics	Small app.	Lighting	Water heating	Ventil ation	IT&C	EV
DR potential	0,7	2,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1
Effective curtailment	0,3	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1

DR potential ■ Effective curtailment

national DSO, ERDF. The participation of water heaters in the peaks is thus very slim.

Residential consumption by equipment type, for a peak winter day, France 2015, Source: basic

The effective curtailment of energy on the French market has been calculated using the total DR potential and applying a series of DR penetration scenarios. The above figure presents the results of the median scenario, where DR program participation figures for 2010 and 2011 reflect the current figures of 12,000 households, and reaching more than 4.5 million households by 2020.

As the above figure shows, the total DR potential of about 3.0 GW corresponds roughly to an effective curtailment of about 0.8 GW. Close to 90% of the curtailment comes from heating equipment. The effective curtailment to potential curtailment ratio is much more favourable in the case of heat pumps, as they are better connected to the panel and can be connected to DR equipment easily.

	Heat pump	Heater	Other central heating	AC	Cooling	Clothes dryer	Washing machine	Dish washer	Cooking	Electro nics	Small app.	Lighting	Water heating	Ventil ation	IT&C	EV
DR potential	3,1	2,2	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,5
Effective curtailment	2,2	1,1	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,4

Source: BASIC

DR potential ■ Effective curtailment

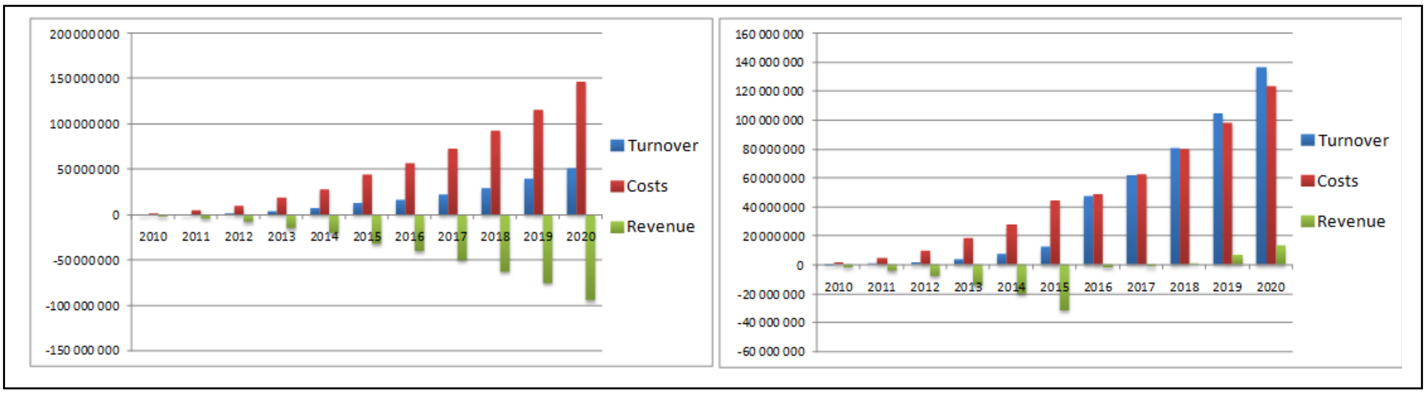
Residential consumption by equipment type, for a peak winter day, France 2020, Source: Basic

The situation changes only slightly in 2020. Total DR potential goes up, neighboring values of about 6.4 GW, with effective curtailment reaching about 3.8 GW. Most of the capacity is again supported by heating equipment, with other equipment registering only marginal participations. The heat pump is set to take over the conventional heater, both in terms of potential and effective curtailment. This is due to the French government's policy of replacing the conventional heater park. In the period 2015–2020, conventional heater potential is expected to remain stable.

With a fleet of between 1.5 and 2 million, the electric vehicle will provide a DR potential of about 0.5 GW by 2020. This potential will probably be easy to convert to an effective curtailment.

Exploiting the associated potential

The French market shows clear potential for large scale residential curtailment, delivered mostly by heating equipment. Yet monetizing this curtailment may be difficult under the current DR participation structures.



<u>**Monetization of demand response in France.** Source: Basic</u>

The graph on the left shows the results of a residential aggregator monetizing DR in the current market situation of an "energy" type DR service, the graph on the right shows the same aggregator in the context of the creation of a capacity market starting in 2016, and valuing DR capacity at €250 per MW.

Without a clear participation model and without the creation of a capacity market, the business model of the residential aggregator will be difficult to improve. The high OPEX associated with the installation of curtailment equipment in each individual household, combined with the 2 to 4 kW of capacity each one of these resources can offer, provide insufficient revenue when commercialized in the current "energy" type market structure. The creation of a capacity market and the correct valuation of resources would lead to an improvement in the aggregator's business model, ensuring the latter strikes even early after the introduction of the service and profits from its activity later on.

Conclusions

The French residential market is very well adapted to Demand Response. A strong dependence on electric heating and previous experience of functional DR programs present the country as a residential curtailment service provider's best bet in Europe. As the consumption model developed by Basic has shown, the country presents important DR potential – more than 3.0 GW now and more than 6.4 GW by 2020 - which can be tapped into fairly easily. The DR market is however paralyzed by poor regulation and insufficient monetization structures. The lack of a capacity market is its biggest flaw. Confusing mechanisms in current "energy" type services also add to the entry barriers faced by aggregators when considering France.

DR is not a priority for the moment, but one can expect that with a saturation of international interconnection lines and a growing participation of intermittent, renewable generation into the energy mix, the current position will change.

References

[1] Basic Consultants. *Study on the European Residential Demand Response Markets*, Multi-client study, 2010. Can be ordered from www.basic-consultants.com.

[2] Basic Consultants & Coda Strategies. *Study on the European Commercial and Industrial Demand Response Markets.* Multi-client study, 2010. Can be ordered from www.basic-consultants.com or www.codastrategies.com.

[3] Commission de Régulation de l'Energie. *Décryptages N° 16, September-October 2009.* Available at www.cre.fr.

[4] www.voltalis.fr

[5] Federal Energy Regulation Commission, *Demand Response Compensation in Organized Wholesale Markets,* 18 March 2010. Available at www.ferc.gov/whats-new/comm-meet/2010/031810/E-1.pdf

[6] www.enernoc.com

[7] www.erdf.fr

[8] Susan Covino *Monitoring and Verification for Demand Response*. Proc. of the PLMA Conference "Demand Response – Reaching its potential", Alexandria, Virginia

[9] Aaron Breidenbaugh *Measurement and verification of DR* Proc. of the PLMA Conference "Demand Response – Reaching its potential", Alexandria, Virginia

Residential Conditional Demand Analysis

K. H. Tiedemann and I. M. Sulyma

BC Hydro

Abstract

End use consumption refers to the consumption of space heating, space cooling, water heating, lighting and other specific uses as opposed to total consumption. This paper presents the methodology and results of an electricity residential end use study for thirteen end uses for British Columbia. The model is called a conditional demand model because it explains and disaggregates energy consumption conditional on the homeowner's ownership of various end use appliances. The paper compares trends in end use consumption over two decades using a series of conditional demand analyses and offers explanations for these trends in end use electricity consumption. The study produced UEC estimates for thirteen end-uses based on a sample of 1,626 residential customers. The results were weighted back to the population of B.C. Hydro customers. As expected, the largest end-uses are primary electric space heating at 4,767 kWh per year and electric water heating at 2,790 kWh per year. Other major end-uses are secondary electric space heating (2,068 kWh per year), lighting (1,992 kWh per year), refrigerator and freezer (1,120 kWh per year), television (409 kWh per year) and electric range, cook top and oven (347 kWh per year).

Introduction

Electric utilities use information on end-use energy consumption for power system planning, load forecasting, marketing and demand side management. End-use consumption refers to the consumption of space heating, space cooling, water heating, lighting, refrigeration, cooking and various plug loads. A key tool for estimating end-use energy consumption is conditional demand analysis, which uses energy billing data combined with weather data and customer survey data in a multivariate regression framework. The basic idea underlying the conditional demand analysis is that the total load in a dwelling can be disaggregated into the component or end-use loads. The model is called a conditional demand model because it explains and disaggregates energy consumption conditional on the homeowner's ownership of various end use appliances. These can in turn be modeled using thermodynamic principles and behavioural information as appropriate.

The conditional demand analysis has several advantages over its main rival of end-use metering. First, surveying customers is inexpensive compared to end-use metering, so that robust estimates can be produced at relatively low cost through conditional demand analysis. Second, the number of sites included in metering projects is often quite small, so that the metered estimates may have large standard errors compared to conditional demand estimates. Third, the conditional demand approach can be used to estimate end-use loads for residential dwellings or dwelling classes not included in the modeling, if appropriate survey based information is available.

The purpose of this paper is to report on and examine the results of a detailed conditional demand study based on a sample of BC Hydro's residential customers. An outline of the paper is as follows. The next section provides a brief review of the relevant literature. This is followed by a discussion of the data used and the statistical method employed. The next section provides the results of the analysis focusing on the estimates of unit energy consumption and end use intensities. The discussion section compares the results of this work with previous conditional demand studies for the same service territory and outlines and discusses trends in unit energy consumption. The last section provides a summary.

Literature Review

The basic idea of the conditional demand model, as developed by Parti and Parti (Lawrence and Parti [1] and Parti and Parti [2]), is that total household consumption is the sum of consumption of various end-uses plus an error term or residual. Appliance saturations are modeled by an indicator variable to indicate the presence or absence of an end-use in a particular household or by a count variable to indicate the number of units present. The estimated regression coefficient is the unit energy coefficient or UEC. The UECs are modeled as functions of appropriate exogenous variables, using a detailed behavioral-thermodynamic approach. In other words, basic thermodynamic relationships are exploited to define equations reflecting energy consumption for major end-uses, and these are modified by behavioral characteristics such as the manner and frequency with which an end-use is employed.

The UECs for the various end-uses are functions of appropriate exogenous variables, such as end-use features, dwelling characteristics, household characteristics and household income. The dependent variable in the model is daily energy consumption per household in a given month, which is obtained from customer billing data by dividing total consumption by the number of days in the billing cycle. Using customers' actual consumption by month allows consumption to be modeled as a function of weather in that month, including the impact of heating degree-days (HDD) on main space heating and supplementary space heating load and the impact of cooling degree-days (CDD) on central air conditioning and portable/room air conditioners. A related concept is that of end use intensity or EUI, which refers to the average consumption per household for a particular end use. The EUI is the average consumption per household for the end use, whether the house has none, one unit or several units for that end use.

Following the initial pioneering work, a number of papers provided extensions and additional applications of the conditional demand method. Sebold and Paris [3] provided a survey of early studies, all very much within the initial framework. In general, they found that with carefully designed surveys and with surveys completed by large samples of customers, it was possible to get a reasonable level of precision around the UEC estimates. Aigner, Sorooshian and P. Kerwin [4] used 15 minute interval data from 100 Los Angeles residential customers to determine hourly regression equations. They imposed restrictive time-windows of appliance use which resulted in improved estimates of UECs for appliances which were used intermittently such as clothes washers or dishwashers. Aigner and Schonfeld [5] built on these insights to develop procedures for optimal sample design for end use metering. Bartels, R. and D.G. Fiebig [6, 7] took the next logical step by integrating direct metering and conditional demand analysis for the estimation of end-use loads. This was accomplished by removing the energy consumption and related end use specification for directly metered loads for both sides of the regression equations to increase the statistical resolution of the estimates for the remaining end uses which were modelled. Tiedemann [8, 9] extended the literature in two directions by first estimating UECs at the regional rather than the system level and by second incorporating estimates of conservation measures into the conditional demand analysis specifications. Larsen and Nesbaken [10] emphasized the critical problem of multi-collinearity for end uses which have high saturation levels and suggested methods for improving CDA estimates.

Data and Estimation

The sample used in conditional demand analysis included the households in B.C. Hydro's service territory who participated in BC Hydro's 2008 Residential End-use Study. For this End-use Study, 20,000 surveys were mailed in June 2008 to a random stratified sample of residential customers across regions and building types in BC. The survey included detailed questions on all major residential end-uses, various electricity consuming behaviours and demographic characteristics of each household. A total of 6,584 surveys were returned, and there were 5,827 customers who agreed BC Hydro to link their end-use information to their billing consumption data for research purpose. The end-use information of 1,626 customers was combined with 25-months of billing data and weather data for the same period and the appropriate region for each customer.

Table 1 shows the distribution of the final sample size of 1,626 homes across four regions and five dwelling types. Compared to BC Hydro's residential billing system, in which about 61% homes are single family detached houses or duplexes, and 34% apartments or row/townhouses, the sample somewhat over represents single detached houses and it somewhat under represents apartments and row houses/townhouses.

Table 1. Distribution of the Sample Used in the Conditional Demand Analysis

	Lower Mainland	Vancouver Island	Southern Interior	Northern Region	Total
Single detached house	200	338	398	292	1,228
Duplex	16	20	29	9	74
Row house or townhouse	38	21	26	5	90
Apartment	49	35	22	6	112
Mobile home	11	18	53	40	122
Total	314	432	528	352	1,626

Previous residential conditional demand studies were reviewed with a view to understanding how other researchers have viewed the trade-off between detailed engineering specifications and a parsimonious design. Richer engineering detail provides improved face validity, but this comes at the expense of potential collinearity problems in the data and less robust estimates. A detailed conditional demand analysis model with fifty-one coefficients was estimated using ordinary least squares. Most coefficients were significant at the five percent confidence level, and all of the coefficients had the expected signs. The adjusted R-squared value of the regression was 0.79 which means that the regression explains seventy-nine percent of the variance in the data. Examination of the residuals from the regression identified no problems with the modeling.

Results

Table 2 shows saturation rates, UECs of electric end uses, and weighted average end use intensities across all regions and housings. Weights were derived by actual proportion of residential accounts in population, and penetration of each end-use in different regions and for different dwelling segments. As expected, the largest end-uses are primary electric space heating at 4,767 kWh per year and electric water heating at 2,790 kWh per year. Other major end-uses are secondary electric space heating (2,068 kWh per year), lighting (1,992 kWh per year), and refrigerator and freezer (1,120 kWh per year). Pools and hot tubs are also heavy users of electricity, but they have rather low saturation rates than other major end-uses. Based on UECs and saturation of each end-use, electricity consumption of each end-use was also estimated for an average home in British Columbia. The annual energy consumption per household (HEC) was estimated as about 10,069 kWh per year, which is comparable to actual average annual electricity consumption of all BC homes in 2008 (10,446 kWh), when accounts with extremely high annual consumption are excluded.

Table 2. Saturation Rates, Unit Energy Consumption and End Use Intensity

End use	Saturation	Unit Energy Consumption (kWh per year)	End Use Intensity (kWh per year)
Primary electric space heating	0.36	4,767	1,716
Secondary electric space heating	0.27	2,068	558
Central air conditioning	0.09	230	21
Electric water heating	0.38	2,790	1,060
Refrigerator or freezer	2.00	1,120	2,240
Electric range, stove, cook top	1.05	347	364
Dishwasher	0.72	372	268
Clothes washer or dryer	1.81	256	463
Lighting	39.47	50	1,992
Television	1.88	409	769
Personal computer	1.25	415	519
Swimming pool	0.004	1,597	6
Hot tub	0.03	2,881	86

Table 3 shows estimated primary electric space heating consumption by geographic region and housing type. On average, the unit energy consumption was 5,253 kWh per year in the Lower Mainland, 6,607 kWh per year on Vancouver Island, 7,953 kWh per year in the Southern Interior and

8,489 kWh per year in the Northern region. The primary space heating consumption varies between the high consuming and the low consuming regions by a factor of two. Considerably more variation exists between different housing types. The difference between unit energy consumption for apartments (2,050 kWh per year) and single detached homes (8,542 kWh per year) varies by a factor of five.

Table 3. Primary Electric Space Heating (kWh per year)

	Lower Mainland	Vancouver Island	Southern Interior	Northern Region	Average
Single detached	7,504	7,351	9,382	10,706	8,542
Duplex	4,720	5,693	6,451	8,693	5,672
Row house/townhouse	5,096	5,570	6,537	8,196	5,630
Apartment	2,043	2,227	2,307	1,958	2,050
Mobile	4,229	6,842	6,877	6,517	6,308
Average	5,253	6,607	7,953	8,489	4,767

Table 4 shows the estimated UECs of electric water heating across regions and building types. The unit energy consumption was 2,471 kWh per year in the Lower Mainland, 2,429 kWh per year on Vancouver Island, 2,957 kWh per year in the Southern Interior and 3,942 kWh per year in the Northern region.

Table 4. Primary Electric Space Heating (kWh per year)

	Lower Mainland	Vancouver Island	Southern Interior	Northern Region	Average
Single detached	2,766	2,578	3,067	4,097	3,118
Duplex	1,989	2,467	2,591	3,766	3,393
Row house/townhouse	2,768	2,282	2,881	4,190	2,960
Apartment	2,015	2,215	2,549	3,486	2,297
Mobile	1,828	1,916	2,933	3,659	2,687
Average	2,471	2,429	2,957	3,942	2,790

Discussion

Table 5 provides a comparison of the residential consumption estimates by end use for the three studies completed to date in 1992, 2004 and 2008 respectively. Note that it was not possible to obtain robust estimates for unit energy consumption for secondary electric space heating or personal computers for 1992 because of low saturation rates. This comparison permits some preliminary generalizations to be made about trends in residential unit energy consumption. Some key findings are as follows:

- The primary electric space heating load fell from 5,526 kWh per year in 1992 to 4,767 kWh per year in 2008. This may be due to improvements in insulation, draft proofing and fenestration products.

- The central air conditioning load continues to be relatively small compared to the corresponding load in many other North American jurisdictions, and it was only 230 kWh per year in 2008, up from 170 kWh per year in 1992.

- The electric water heating load fell from 5,995 kWh per year in 1992 to 2,790 kWh per year in 2008. This reduction may be due to improvements in the insulation in water heaters, increased issue of pipe wrap, and increased saturation of low flow showerheads and aerators.

- The lighting load rose from 1,037 kWh per year in 1992 to 1,992 kWh per year in 2008. There is some evidence that the efficiency gains from customers switching from Type A lamps to CFLs may have been more than overcome by increased saturation of high wattage halogen torchieres.

- The load for electric ranges and other cooking fell from 889 kWh per year in 1992 to 347 kWh per year in 2008, and this may be due to the increased use of microwave ovens and to an increased share of meals eaten outside the home.

- Refrigerator and freezer loads fell from 1,274 kWh per year in 1992 to 1,120 kWh per year in 2008, and this probably reflects the trade off between two opposite trends: first, increased use of automatic defrost refrigerators which use more electricity than comparable manual defrost refrigerators, and second, increased efficiency of automatic defrost refrigerators because of federal minimum energy performance standards.

It is worth noting that in the absence of periodically conducted detailed metering studies, conditional demand analysis is an efficient means of understanding trends in end use consumption, because many utilities routinely conduct end use surveys of their customers as part of their market research efforts.

Table 5. Comparison of Unit Energy Consumption Estimates (kWh per year)

End use	1992 Results	2004 Results	2008 Results
Primary electric space heating	5,526	5,037	4,767
Secondary electric space heating	-	2,310	2,068
Central air conditioning	170	346	230
Electric water heating	5,995	3,186	2,790
Refrigerator or freezer	1,274	1,112	1,120
Electric range, stove, cook top	889	721	347
Dishwasher	217	380	372
Clothes washer or dryer	465	648	256
Lighting	1,037	1,937	1,992
Television	900	878	409
Personal computer	-	656	415
Swimming pool	3,113	1,912	1,597
Hot tub	3,819	2,628	2,881

Conclusions

Electric utilities use information on end-use energy consumption for power system planning, load forecasting, marketing and demand side management. End-use consumption refers to the consumption of space heating, space cooling, water heating, lighting and other specific uses as opposed to total consumption. This report presents the methodology and results of a residential end-use study for B.C. Hydro’s service territory. The study used conditional demand analysis (CDA) to estimate unit energy consumption (UEC) values for several residential end-uses. The model is called a conditional demand model because it explains and disaggregates energy consumption conditional on the homeowner’s ownership of various end use appliances. CDA is a multivariate regression technique which combines utility billing data with weather information and customer survey data.

The study produced UEC estimates for thirteen end-uses based on a sample of 1,626 residential customers. The results were weighted back to the population of B.C. Hydro customers. As expected, the largest end-uses are primary electric space heating at 4,767 kWh per year and electric water heating at 2,790 kWh per year. Other major end-uses are secondary electric space heating (2,068 kWh per year), lighting (1,992 kWh per year), refrigerator and freezer (1,120 kWh per year), television (409 kWh per year) and electric range, cook top and oven (347 kWh per year). The analysis found significant variation in space heating consumption across geographic areas and housing types. On average, the unit energy consumption was 5,253 kWh per year in the Lower Mainland, 6,607 kWh per year on Vancouver Island, 7,953 kWh per year in the Southern Interior and 8,489 kWh per year in the Northern region. Considerably variation exists between different housing types. A similar but less extreme pattern occurs for electric water heating consumption. The unit energy consumption was 2,471 kWh per year in the Lower Mainland, 2,429 kWh per year on Vancouver Island, 2,957 kWh per year in the Southern Interior and 3,942 kWh per year in the Northern region.

Acknowledgements

I wish to thank Min Yu for her assistance with the statistical analysis and Joe Kelly, David Sumi and Ed Vine for comments and suggestions on an earlier version of this work. They are not of course responsible for any errors or omissions.

References

[1] Lawrence D. and Parti M. *Survey of Conditional Energy Demand Models for Estimating Residential Unit Energy Consumption Coefficients.* EPRI Report No. EA-3410, 1984.

[2] Parti C. and Parti M. *Total and appliance-specific demand for electricity in the household sector.* Bell Journal of Economics, Spring 1989, pp. 309-324.

[3] Sebold F. and Paris K. *Residential End-use Energy Consumption: A Survey of Estimates.* EPRI Report No. CU-6487, 1989.

[4] Aigner D., Sorooshian C. and Kerwin P. *Conditional demand analysis for estimating residual end-use load profiles.* Energy Journal 1990, pp. 81-97.

[5] Aigner D. and Schonfeld P. *Experimental design for direct metering of residential end-uses*. In Gabszewitcz et al. eds. Economic Decision-Making: Games, Econometrics and Optimisation. Elsevier Science Publishers: 1990.

[6] Bartels R. and Fiebig D. *Integrating direct metering and conditional demand analysis for estimating end-use loads.* Energy Journal 1990, pp. 79-97.

[7] Bartels R. and Fiebig D. *Residential end-use electricity demand: results from a designed experiment.* Energy Journal 2000, pp. 51-81.

[8] Tiedemann K. *Estimating residential end-use energy consumption.* Proceedings of the Eleventh Annual Symposium on Geographical Information Systems, 1997, pp. 616-618.

[9] Tiedemann K. *Statistical modelling of end-use energy consumption using a residential panel.* Proceedings of the 5th International Conference on Probability Methods Applied to Power Systems, pp. 398-342.

[10] Larsen B. and Nesbaken R. *How to Quantify Household Electricity End-use Consumption.* Statistics Norway Discussion Paper No. 346, March 2002.

A functional analysis of electrical load curve modelling for some households specific electricity end-uses

Arnaud GRANDJEAN[a,b], Guillaume BINET[a], Jean BIERET[a], Jérôme ADNOT[b], Bruno DUPLESSIS[b]

[a]EDF R&D, Énergies des Bâtiments et des Territoires (EnerBat), [b]École Nationale Supérieure des Mines de Paris (Mines ParisTech)

Abstract

In the next decades the European residential sector will face a series of deep technical and behavioural breaks. Among them are : the integration of new electrical domestic end-uses, the development of plug-in hybrid and electric vehicles, the increase of heat pumps implementations, the improvement and the technological changes in small electrical appliances. This will imply some behavioural modifications in the lifestyles. For example, the wishes in terms of comfort and the way electrical devices are used will evolve significantly. The energy consumption is likely to increase but the residential load curve will also be strongly modified. We then propose a functional analysis which enables to take into account, for each end-use, according to its own specificities, the key points that allow to build-up a relevant load curve. This will lead us to step down at the appliance level which will be the starting point of our modelling method. After a general description of the methodology, we will present three case studies for the following end-uses: washing, cooling and lighting. We will consider for each device the main determining factors of which are the technical features, the occupancy patterns of the household members, the activity scenarios in the dwellings, the climate. This bottom-up approach will generate intrinsically some kind of diversity needed to represent the temporality and the level of the power demand for a large number of households. This methodology allows, after an aggregation step, the calculation of the load curves for households at various spatial scales.

Introduction

In France in 2008, the buildings (housing stock) are responsible for 27%[1] of the final energy demand and 16%[2] of the GHG emissions. That is to say that some efforts in demand side management should have noticeable impacts on these two indicators. Contrary to the industry field demand which is quite steady on a day basis, the buildings, depending on the human presence and activities, are characterized by a fluctuating power demand when considering a unique day and between different days in a year. In the near future, the power demand profile will be completely different from what it is today because of many influences:

- best building insulation which will reduce the energy needs for heating and cooling;
- new comfort levels and management scenarios in the dwellings;
- possible huge integration of electrical heating systems such as heat pumps in new building or which will replace old installed fossil fuels based systems;
- integration of new end-uses such as Plug-in Electric Vehicles and an always growing number of electrical devices;
- integration of decentralized energy production and stocking (PV modules with battery for example);

[1] MEDDTL source

[2] CITEPA source

- new energy prices which will influence the time of use of the domestic appliances.

These evolutions will lead to a modified electrical demand (in terms of consumption) but simultaneously to a very different aggregated load curve (electric power demand over the time). This last representation is very dependent on the time of use and on the way (intensity of functioning) appliances are used. Then the peak load issue on the electric network, which is one of its main dimensioning characteristics, could evolve significantly in terms of shape and level.

That’s the reason why the load shape estimation is taking a more and more important role especially in the residential sector where there are no aggregated measurements. In the literature we can find three main types of models:

1. top-down models which analyze total load curves measured on a sample of dwellings in order to get end-uses load curves;

2. bottom-up methodologies that build the load curve from an elementary entity that could be the domestic appliance, the end-use or even the household and aggregate it at the wished modelling level;

3. hybrid methods that combine both bottom-up and top-down approaches.

Various models have been developed according to each typology of method. Yet top-down approaches like what was constructed by Aigner et al. [1] or Bartels et al. [2] fail for the load forecasts in case of non-trend evolutions because of the use of past measures. In order to take into account the future changes the residential sector is likely to face, an estimation model must be explicit in terms of technology that is to say to calculate the load curves with focus on the domestic appliances, their technical characteristics and the ways they are used by the occupants as starting points. A literature survey has identified a series of bottom-up models [3, 4, 5, 6, 7, 8, 9, 10 and 11]. Finally hybrid methods were notably used by Train et al. [12, 13]. Yet all those models don’t answer very well to the exposed problem.

Thus we choose the bottom-up approach for our model because it fits the best our needs.

Then we conducted a **functional analysis** enabling to achieve the aimed sophistication of the modelling. In a first time we describe our method. Then we expose the routine of the methodology in order to simulate a specific end-use according to its own characteristics. Finally we conclude on the future possible improvements of our method.

Presentation of the modelling methodology

The aim of the model is to get, for selected simulation duration (up to several decades), daily load curves corresponding to a specified household stock on a territory: the so called **inhabited stock**. This is constituted by three main entities: **typical buildings**, **typical households** and **typical appliances**[3]. The association of a typical building, a typical household and a set of typical appliances constitutes an **n-tuple**. This segmentation is a result of the functional analysis which showed that the optimal way to calculate domestic load curves has to take into account these influences independently. Moreover it enables an easier management of the evolution of the inhabited stock.

We only chose a reduced number of parameters so as to define the typical elements and we selected a restricted series of domestic appliances because of two main statements of facts:

- in reality each element in the simulated stock could be defined with an important amount of characteristics, themselves show a large diversity;

- our choices focus on the most relevant influences for the domestic power demand.

[3] In the rest of this paper, we will alternately use the following nomenclature to design the typical elements too: building-type, household-type and appliance-type.

Therefore our method intrinsically ignores certain diversity sources that are inconceivable to model. For instance some domestic appliances are not considered: we call them the **unexplained appliances**. The model doesn't give any individual load curve for these devices. Yet, these are responsible for certain energy consumption: we call this quantity the **inevitable energy balance**. We have to integrate it in our model that is to say to give it a corresponding load curve pattern.

The developed method is based on four main functions which are explained in details in the following sections. Because of our choices concerning the appliances we present in this paper, we focus the explanations on the procedures and functions of the model that are indispensable for their simulation. The architecture of the methodology is presented in Figure 1.

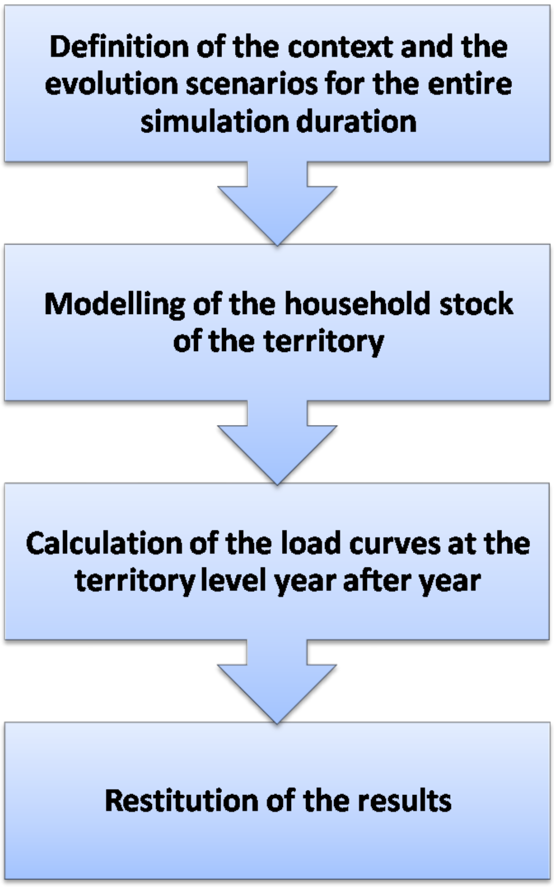


Figure 1 : Architecture of the load curve reconstitution method

Definition of the context and the evolution scenarios for the entire simulation duration

The first step is to define the temporal scale of the simulation. Concretely, **key events** have to be programmed and set at an annual scale in order to materialize behavioural and technological breaks which are likely to happen during the whole simulation. These events could modify individually the net flows of each typical element[4] and/or the inevitable energy balance[5]. We call **period** the temporal range between two consecutive key events. On top of the changes in the inhabited stock in terms of breaks, annual evolutions of the simulated entities have to be inserted in the modelling scenario. Thus the user has to define for each period net flows evolution for each typical entity and for the inevitable

[4] key events could be define specifically for a typical building, a typical household or a typical appliance

[5] key events which only affect the inevitable energy balance could be set

energy balance. These evolutions could be based on mathematical functions such as linear growth or decrease, exponential evolution, sinusoidal trend. In Figure 2, we propose an illustration of these previous concepts where five different key events (e_i) have been defined throughout the simulation duration. We can underline that the penetration rate of the appliances a_2 and a_3 are directly

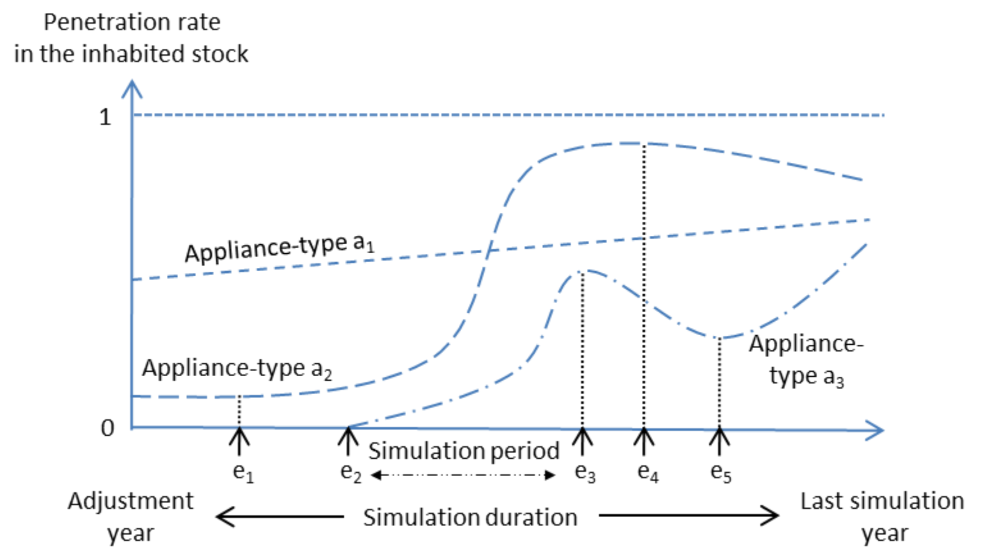


Figure 2 : Penetration rate evolutions for some typical appliances

dependent on the key events what is not the case of the typical appliance a_1 whose saturation rate follows a linear growth during the simulation.

Modelling of the household stock of the territory

In this section, we describe the method used to characterize the geographical and technical dimensions of the simulation. In fact, the inhabited stock corresponds to a territory which could be divided into some **geographical zones** in accordance with the weather variability on the territory. We first have to define the typical elements constituting the inhabited stock. We then have to construct it for each geographical zone and year. Finally we must ensure the coherence of the proportions of each n-tuple at the territory level.

Definition of the typical elements of the inhabited stock

As we previously said, the inhabited stock is constituted with three main elements:

1. **typical buildings** are characterized with five parameters: dwelling type, dwelling area, global insulation, inertia and ventilation type;

2. **typical households** are defined with four characteristics: composition, socio-economical level, occupation status (active, retired...) and general behaviour towards energy consumption;

3. **typical appliances** are classified according to their corresponding domestic end-use (domestic cold, washing, lighting...) and more precisely characterized with three sets of parameters: nomenclature, functional parameters and control variables.

The typical elements take the form of three **libraries** (see Figure 3), that's to say that the model user may choose each element needed for a simulation in the corresponding one.

In the following tables, we present an example of a building-type (Table 1), a household-type (Table 2) and several typical appliances (Table 3).

Table 1 : Example of a typical building

Properties	Modalities and values
Dwelling type	Detached house
Dwelling area	120m²
Global insulation	1.0W/m².K
Intertia	200kJ/m².K
Ventilation type	Heat recovery ventilation

Table 2 : Example of a typical household

Properties	Modalities and values
Composition	2 adults, 2 children
Socio-economical characteristics	Medium income
Occupation status	Active
Behavior towards energy consumption	
Heating/cooling	Energetically responsible
Electricity specific	Indifferent

Table 3 : Examples of typical appliances

Properties	Modalities and values			
Nomenclature				
Corresponding end-use	Domestic cold	Clothes washing	Lighting	
Appliance name	Fridge F_3	Washing-machine WM_4	Light-bulb Lb_1	Light-bulb Lb_2
Appliance nature	Nomade appliance	Nomade appliance	Nomade appliance	Nomade appliance
Functioning parameters				
Energy grade	B	A+	A	A
Nominal wattage	-	-	80W	50W
Functioning mode(s)	2°C, 4°C, 6°C	30°C, 60°C, 90°C, eco-mode	-	-
Cycle(s) duration	1-5min	75, 85, 100, 45min	-	-
Unitary load cycle(s)	Available in database	Available in database	To be defined	To be defined
Adapted consumption function	No	Yes	-	-
Control variables				
Load shedding adapted	No	Yes	No	No
Programmable	No	Yes	Yes	Yes
Functioning constraints	Non-stop functioning	Runs before the tumble-dryer	-	-

Construction of the inhabited stock for each geographical zone

The above defined typical elements have to be then assembled so as to constitute the n-tuples. The association is based on logic rules and affectation laws so that the complete combinatory of all the typical elements isn't carried out: only the possible combinations are allowed. In this function we associate them according to the geographical area and the simulated year considered. As a result, we get an **n-tuple data basis**. Thus we differentiate this process between the first simulation year, the so called **adjustment**[6] **year**, and any other year of the simulation. In fact in the first case the complete association has to be proceeded: we call this the **historical inhabited stock.** On the contrary, in any other case only the modifications affecting the n-tuples with regard to the historical inhabited stock have to be implemented.

The construction of the historical inhabited stock, schematically illustrated in Figure 3, is a four-step operation:

1. definition of the proportions (numbers) of each typical building in the inhabited stock;

2. definition of the proportions (numbers) of each typical household for each typical building. This association depends on the characteristics of the typical household particularly the socio-economical parameters and the composition of the family;

3. distribution of the typical appliances for each couple typical building / typical household. Here again the parameters values of each typical element guide the association of them because the most and less probably combinations are identified;

4. definition of the participation of each n-tuple in the inevitable energy balance. According to the characteristics of the n-tuple (domestic appliance set, behaviour of the household's members…), each of them is responsible for certain unexplained energy consumption.

The modelling of the inhabited stock for another year is a much more complicated task. According to the key events previously defined, all kinds of modifications concerning the n-tuples have to be integrated year after year. Thus on top of deep changes as technological breaks and behaviour modifications which impose the creation of new typical elements, the ageing of each element[7] must be taken into consideration. This leads to the definition of elements' **generations** in the inhabited stock. Moreover there is an obvious evolution consisting in the possible modification of each element's proportion and the n-tuple participations in the inevitable energy balance.

---

[6] for this year real data are available: energy measurements, domestic load curves, saturation levels for a majority of appliances…

[7] with the exception of the ageing of the people in the households. This influence could be taken into account with modifying the proportions of each typical household in the inhabited stock

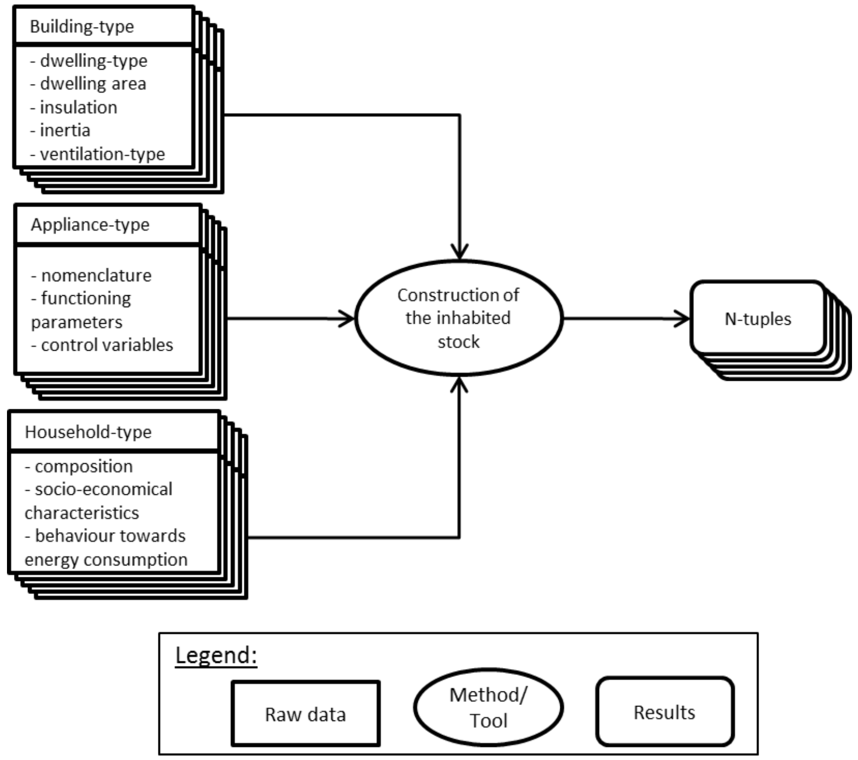


Figure 3 : N-tuples generation processing

Coherence control of the n-tuple proportions in the inhabited stock at the territory level

Because of the construction of the inhabited stock at the geographical zone level and the possible need of the aggregated[8] model results, a coherence control of the n-tuple proportions in the inhabited stock at the territory level seems to be indispensable.

Calculation of the load curves at the territory level year after year

Now that inhabited stock has been defined, the model has then to calculate the corresponding load curves for each n-tuple of the modelled stock. Here is the main richness of the method. This task is realized thanks to a series of functions that are explained in the following paragraphs. The calculation of the load curves is run at the geographical zone level so as to take into account the weather influences on the domestic power demand. Moreover the maximum duration for this calculation is one year because the inhabited stock is unchanged at this temporal scale.

Construction of the simulation calendar for each period

In order to create a simulation calendar, the first thing to do is to select a weather data series from real measurements for the regarded geographical zone and to analyze it. On top of the raw weather data such as outdoor temperature, cloud covering and solar radiation, this step enables the filling of the attributes of each simulated day:

1. season
2. working day (yes / no)
3. holidays period (yes / no)
4. freezing cold (yes / no)

[8] that is to say for the entire territory

5. scorching heat (yes / no)

6. established regime[9] (yes / no)

After that, **typical days**[10] have to be defined: it is a question of generic 24 simulated hours whose characteristics represent the transverse lifestyles of the population. A typical day is constituted by several density functions which give information concerning the start and the end of the domestic activities in the households[11] and the proclivity of the n-tuples for using a specific end-use. Our method contains various typical days that are available under a library form (see Figure 5).

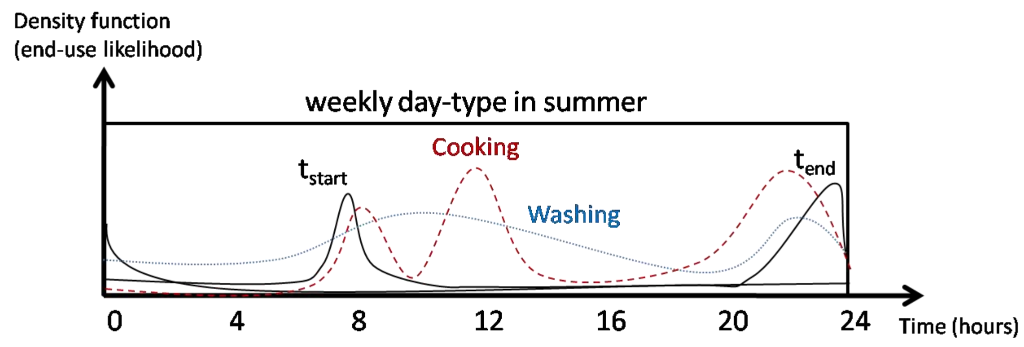


Figure 4 : Example of a day-type

The end of this step consists in establishing a correspondence between the typical and the simulated calendar days. These must be identified with one of the typical 24-hour duration defined above.

Calculation of the unitary load curves for each n-tuple and each simulated day

A **unitary load curve** is a daily load curve for a specified typical appliance used by a selected n-tuple. The calculation of these elements depends on the modelled end-uses: thus we separately consider appliances for heating, cooling, domestic hot water, ventilation and their respective auxiliary devices on the one hand and specific electricity equipment on the other. In this paper, we only discuss the second calculation way because of the chosen devices.

The calculation method that provides the unitary load curves is an iterative process which consider at each step one typical appliance owned by one specified n-tuple. It calculates the corresponding load curve of this device with regard to the day-type and the behaviour of the n-tuple following a four-step process:

1. definition of a **Time of Use scenario**[12] **(TOU)** from the time-series use charts[13] corresponding to the typical appliance (or the end-use). This must respect the coherence with the other selected TOU scenarios for the same n-tuple (there is an end-use diversity inside a household);

---

[9] this attribute tells if the simulated day correspond to the beginning, the middle or the end of an unusual weather event

[10] called day-type too

[11] it corresponds more or less to the waking-up and the bedtime ranges in the population

[12] a TOU scenario contains the start time(s) at the day level of each typical appliance

[13] the time-series charts come from real time use survey in the population and they are available under a library form in the model (cf.Figure 5)

2. definition of a **unitary load cycle**[14] for the selected typical appliance and day-type;

3. attribution of representativeness weights for the all-appliances-considered TOU scenarios;

4. attribution of the functioning mode(s) on the defined TOU scenario for each typical appliance and for the selected day-type.

We represent schematically in Figure 5 the iterative processing which give the unitary load curves. This method has to be repeated for each typical appliance of the considered n-tuple.

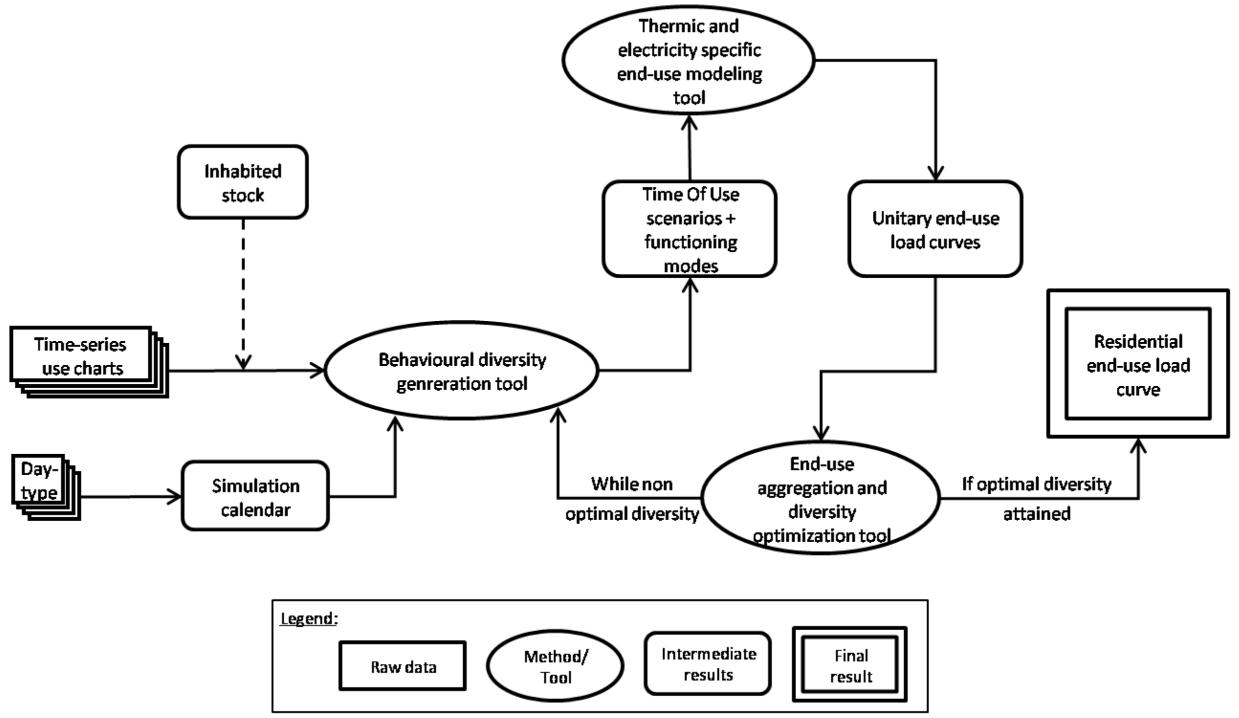


Figure 5 : Unitary load curves generation processing

Calculation of the load profiles for each n-tuple and each simulated day

A **load profile** is the after diversity daily mean load curve for a specified typical appliance, a selected n-tuple and according to the characteristics of the simulated day. This specific load curve is supposed to capture the whole diversity affecting this device. Its construction relies on a four-step method:

1. generation and summation of N unitary load curves and division by N;

2. generation of N’ unitary load curves and summation of the N+N’ unitary elements, division by N+N’;

3. comparison between the two mean load curves previously obtained;

4. pursuit of the process until either the satisfaction of the predefined convergence criterion or the number of people for this n-tuple in the simulated population.

[14] a unitary load cycle is the power demand of an appliance for one of its functioning mode

In Figure 6 we schematically expose the way enabling the construction of the load profiles.

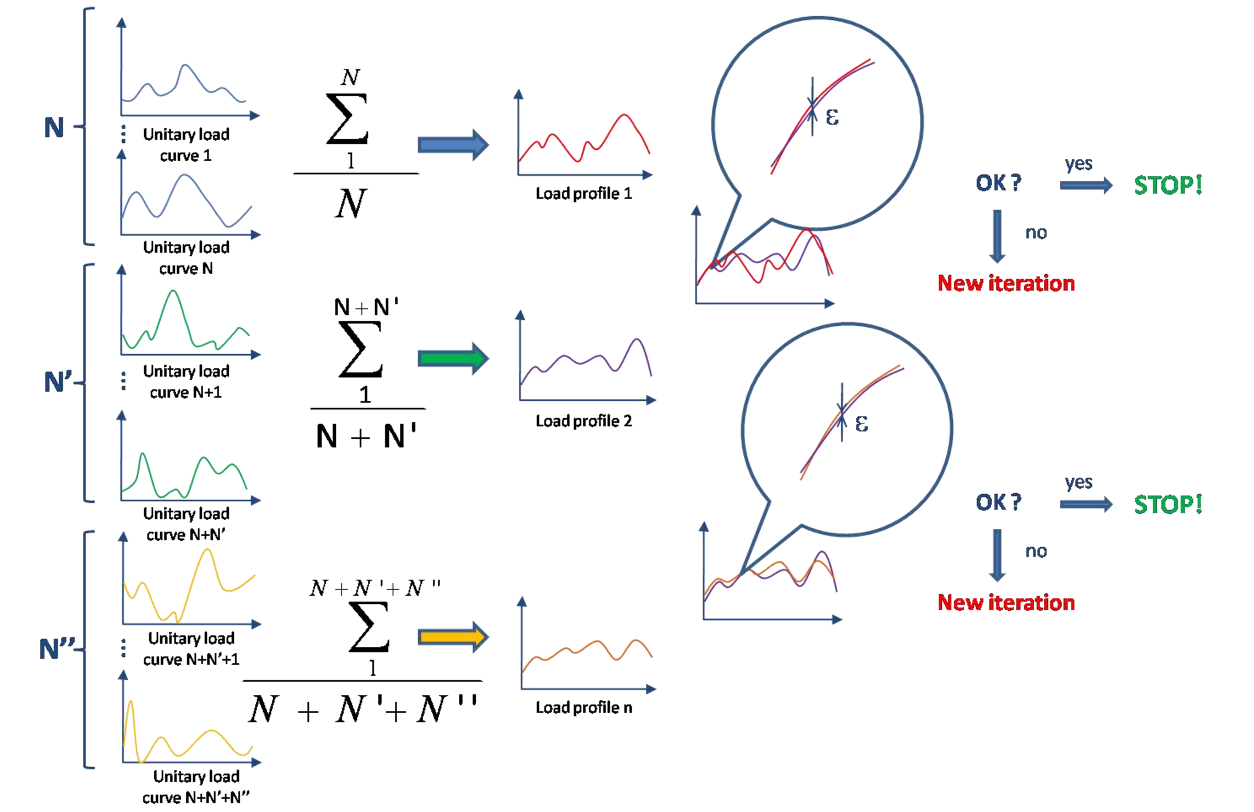


Figure 6 : Load profiles construction processing

In order to get all the load profiles in the population, the previous process must be repeated for each typical appliance in the same n-tuple and for all the n-tuples in the inhabited stock. Convergence criteria could be defined with help of a preliminary study for each typical appliance or end-use. This study would provide some insights concerning the number magnitude of unitary load curves which must be aggregated to obtain the whole diversity that affects this level.

Aggregation of the unitary load curves for all n-tuples and each geographical zone

This function aggregates the previously obtained results in order to get load curves for the global population of the regarded geographical area.

Figure 7 shows the different scaling and aggregation phases that we describe in the next lines.

In the first place – case a) – load profiles have to be scaled at the n-tuple level with respect to its proportion in the inhabited stock[15]. That is to say that each calculated load profile must be multiplied by the size of the corresponding n-tuple (here 350). Thus the daily load curve for each typical appliance, each simulated day, which is function of the n-tuple and for a specified geographical zone is provided thanks to this processing.

In a second step – case b), aggregations by end-use for all the people of the same n-tuple give end-use load curves for each simulated day at the geographical zone level. They are interesting intermediate results that are reused in a following function.

[15] in this case, the inhabited stock represents a population of 1000 n-tuples. 35% of the inhabited stock is constituted by the n-tuple n_1

The daily end-use load curves could be wished for all the people in the geographical zone. That is to say that an aggregation of the end-use load curves for the entire population at the geographical zone level and on the day basis is required. This step is represented in case c).

Finally the end-use load curve for the simulated year and at the geographical zone level could be obtained – case d) – thanks to the concatenation of the previous intermediate results.

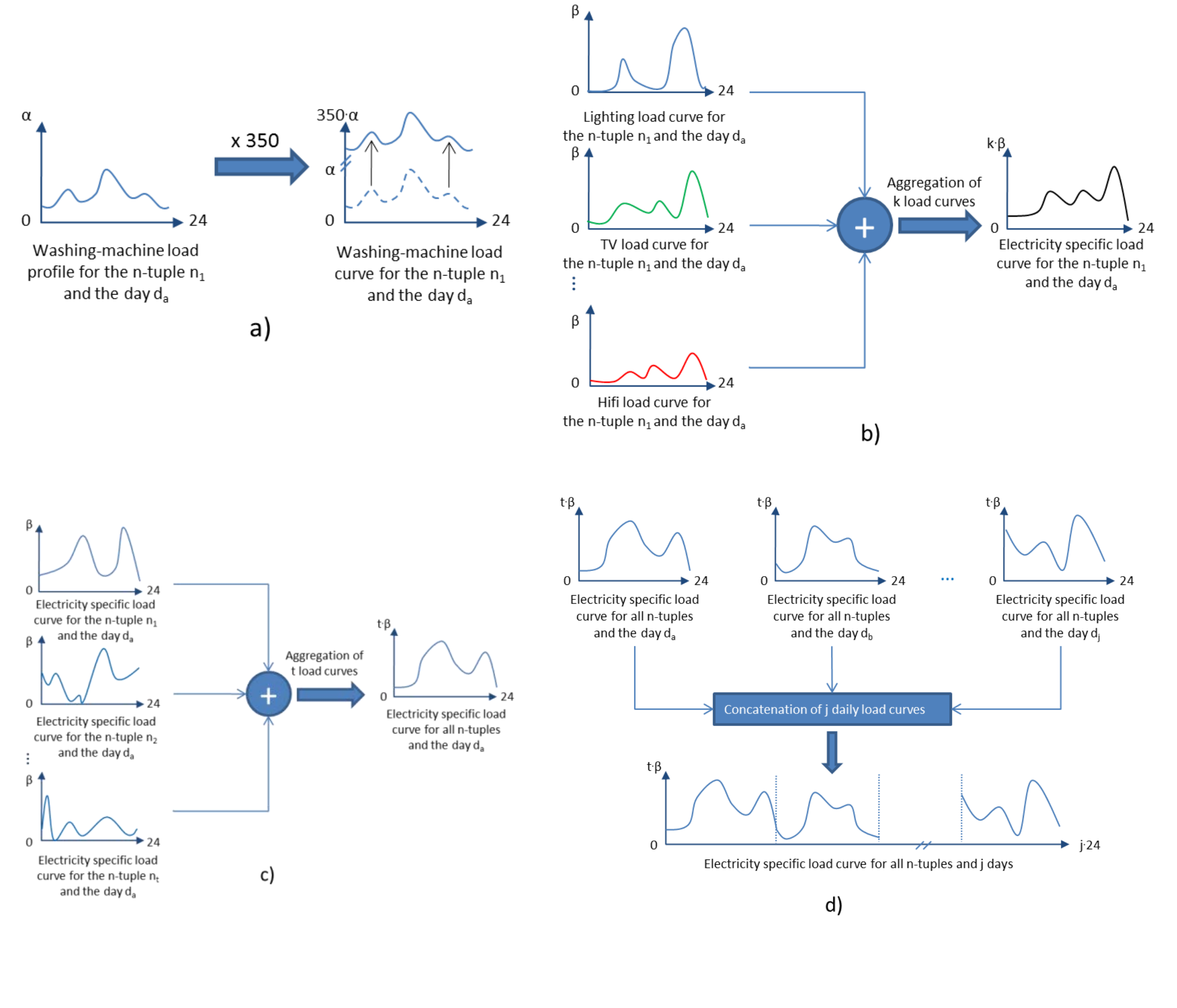


Figure 7 : Load curves aggregation and concatenation processing

Insurance of the energy coherence for the typical appliances load curves

The results of the model must be as good as possible in terms of power demand but even in electricity consumption too. Thus we have to ensure the energy coherence of the yearly end-use load curves. This work could only be conducted with comparison data. More precisely it supposes the use of real end-use[16] consumption measurements (data sources could be various[17]). That's the reason why this task is only valid for the adjustment year.

[16] for example in the case of the specific electricity end-uses, yearly consumption data are a minima available for the washing, the domestic cold, and the lighting (CEREN)

In order to realize this operation, the consumption corresponding to the modelled load curves[18] has to be calculated. So as to get these values, the corresponding integrals have to be evaluated.

In a second step, the comparison between real end-use measurements data and the previously obtained consumptions have to be conducted in order to know if the model coincides with reality.

Then according to the sign of the differences and their magnitudes by end-use, the input data and more precisely the time-series charts and functioning modes of the concerned typical appliances have to be adapted so as to converge on the predefined consumption target according to preselected **convergence criteria**[19]. In fact, we limit for this task the possible modifications on these two input data because of their influence in terms of use intensity and frequency. Moreover it seems complicated to adjust a model when allowing a modification of its whole parameters.

Validation of the results on measured load curves

After having ensured the energy consumption coherence of the model in the previous function, the next step is the validation of the results on measured load curves. Here again this work may only be viable for the adjustment year. The aim of this function is to proceed to a visual comparison between different load curves, comparison which could be formalized with the help of the calculation of load curve specific indicators and other parameters such as:

- the Normalized Variation Factor (NVF) [4, 5, 6, 13] :

$$NVF = \frac{1}{n} \cdot \frac{\sum_n \left(p_{mea}(t) - p_{\mathrm{mod}}(t)\right)^2}{\left(\frac{1}{n}\sum_n p_{mea}(t)\right)^2}$$

  with $p_{mea}(t)$ is the measured power demand at the time step t (n time steps) and $p_{\mathrm{mod}}(t)$ is the modeled power demand at the same time step;

- the Mean Absolute Percentage Error (MAPE) [14] :

$$MAPE = \frac{1}{n}\sum_n \left| \frac{P_{mea}(t) - P_{\mathrm{mod}}(t)}{P_{mea}(t)} \right|$$

  where $p_{mea}(t)$ and $p_{\mathrm{mod}}(t)$ have the same meanings as for the NVF;

- the load factor L_f on the time interval Δt :

$$L_f(\Delta t) = \frac{\overline{P}(\Delta t)}{P_{\max}(\Delta t)}$$

  with $\overline{P}(\Delta t)$ the mean power demand on the time interval Δt and $P_{\max}(\Delta t)$ the maximum power demand on the same time interval;

---

[17] CEREN, REMODECE, ADEME, Panel…

[18] load curves of the typical appliances

[19] it might be useful to set different precision levels depending on the end-uses

- the diversity factor $K_m(\Delta t)$ [20] for m individual consumers :

$$K_m(\Delta t) = \frac{\sum_{j=1}^{m} P_{\max,j}(\Delta t)}{P_{\max,m}(\Delta t)}$$

  with $P_{\max,j}(\Delta t)$ is the maximum power demand of the individual consumer j on the time interval Δt and $P_{\max,m}(\Delta t)$ is the maximum power demand on the interval Δt of the m consumers together considered;

- descriptive statistics elements: $\overline{P}(\Delta t)$, $P_{\max}(\Delta t)$, $\sigma_P(\Delta t)$ (standard deviation of the power demand on the time interval Δt), distribution of the power demand values.

Calculation of the inevitable energy balance at the territory level

As we previously said, the model precisely considers a restricted series of domestic appliances, the other are not explained. That's the reason why we introduce an additional consumption called inevitable energy balance; this quantity has to be calculated year after year. The adjective inevitable stress the fact that the model systematically forgets certain electricity consumption for each simulated n-tuple.

Because of the geographical availability level of the measured data which play the role of references, the inevitable energy balance could be only calculated at the territory level. Moreover this consumption simply concerns electricity specific equipment whose seasonality is ignored. Concretely the inevitable energy balance is the difference between the total consumption from electricity specific appliances and the consumed energy caused by the typical electricity specific appliances. Yet the calculation of this quantify depends on the considered year. In the first case of the adjustment year, the inevitable energy balance is estimated thanks to the reference data. In the second case when considering a year at the beginning of a period and if the set of explained typical electricity specific appliances has changed[21], the inevitable energy balance is obtained with removing the corresponding consumption of the new explained device(s). Finally in any other case (non specific year) the inevitable energy balance is estimated with respect of the evolution scenario that has been previously defined.

Repartition of the inevitable energy balance at the geographical zone level

The previously calculated energy balance may be distributed from the territory level to the geographical zone level. This is made possible thanks to the n-tuples' participations in the inevitable energy balance that were defined when assembling the typical elements to construct the inhabited stock. With these numbers each n-tuple element is responsible for certain additional energy consumption and because of the knowledge of the n-tuple composition of the inhabited stock at the geographical level, the repartition of the inevitable energy balance at this local scale is obtained. In fact, this is the first task of this function whose final aim is to give a load curve pattern for the inevitable energy balance.

In order to do that, the method uses the following hypothesis: for a simulated day, a specified n-tuple in a geographical zone, the load curve representing its share of inevitable energy balance is the same (modulo the consumption, i.e. its integral) as its electricity specific daily load curve. Moreover the distribution of this energy consumption could be done according to the day-type. That is to say that the inevitable energy balance may be affected day after day with respect to the daily consumption of the typical specific electricity appliances for the n-tuple considered. Thus at the geographical zone level, the end result of the model for an end-use is the aggregation of its modelled power demand

[20] or its inverse because of the most interesting variation range [0; 1]

[21] typically an unexplained end-use or typical appliance becomes explained

(sum of the related typical appliances) and if need be the power demand pattern from the inevitable energy balance.

Aggregation of the load curves for each end-use at the territory level

A last aggregation step could be proceeded in order to get the end-use load curves at the territory level that take into account the inevitable energy balance.

Restitution of the results

Different restitution formats may be wished according to the simulation and the results considered. That is the reason why some post processing functions have been integrated in our methodology.

Selection of the formats for the restitution of the results

In this function the user could specify the aggregation level of the load curves. That's to say that the results may be assembled end-use by end-use, according to the end-use families (consumption items) or even all end-uses considered.

Selection of the restitution's temporal and geographical scales

The temporal and geographical scales of the results' restitution consist in filtering through the load curves. Thus it may be possible to wish results for a unique geographical zone, an aggregation of some zones which doesn't coincide necessarily with the territory or the whole territory itself. Concerning the temporal restitution's scale, the user may be interested in obtaining the load curves at a daily, weekly, monthly, seasonally or yearly basis.

Calculation of some indicators and graphical representation of the results

This last function helps the user so that he could easier visualize the results thanks to graphical representations and some load curve specific indicators. On top of the parameters that were previously defined, this function is notably aimed to calculate the thermic gradient (for heating and cooling) and to represent the power demand monotone (classification of the power demand values according to the magnitude and the duration of the demand).

Application of the methods on different case studies

In this section, we use the load curve reconstitution method for three different end-uses: the fridge, the washing-machine and the lighting. These cases have been chosen because of their significant dissimilarities. Despite this fact, the method is able to adapt the processing according to them. In the following paragraphs we present the main particularities of each end-use and the way the method takes them into account through a detailed case study. For these, we choose a specific n-tuple whose characteristics are given in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.** and we apply our method in order to obtain two daily load curves (so two typical days): one for a weekday and another for a weekend day

Modelling of the fridge

Specificities

Fridge is characterized by two kinds of functioning particularities. First it works continuously and without any necessary human presence during a simulation because of the needed permanent cold to a preserving aim. Secondly its functioning is typically cyclic; the duration and the power demand magnitude of each of them depend on the use scenarios which include openings and closings of the door (principally at breakfast and mealtimes) and fillings (restocking) after doing shopping.

In Figure 8 we present several unitary load cycles for an illustrative[22] purpose. Example a) may correspond to a normal functioning without any disruption (steady state). An ideal cyclic functioning is also notable: each power demand event shows the same duration, shape and magnitude. Case b)

[22] these come not from load curve measurements

represents the power demand sequence that could happen just after an opening and a re-filling of the fridge. This causes an increased power demand at direct following cycles which are longer than in steady state too. Load cycles sequence c) only shows a longer power demand for one of them that could be explained by an opening of the fridge door which occurred between the first and the second load cycle. The removing of items out of the fridge theoretically may lead to a reduction of the power demand of this device: magnitude and duration of each unitary load cycle compared with the steady state is normally detectable on appropriate load curve measurements. Finally, case d) could be the power demand for steady state with a lower temperature set than in case a).

With data from a measure campaign another comparisons could be conducted between different fridges. This may probably identify the consequences on the load cycles of non equivalent devices, more precisely in terms of volume, construction year, energetic grade…

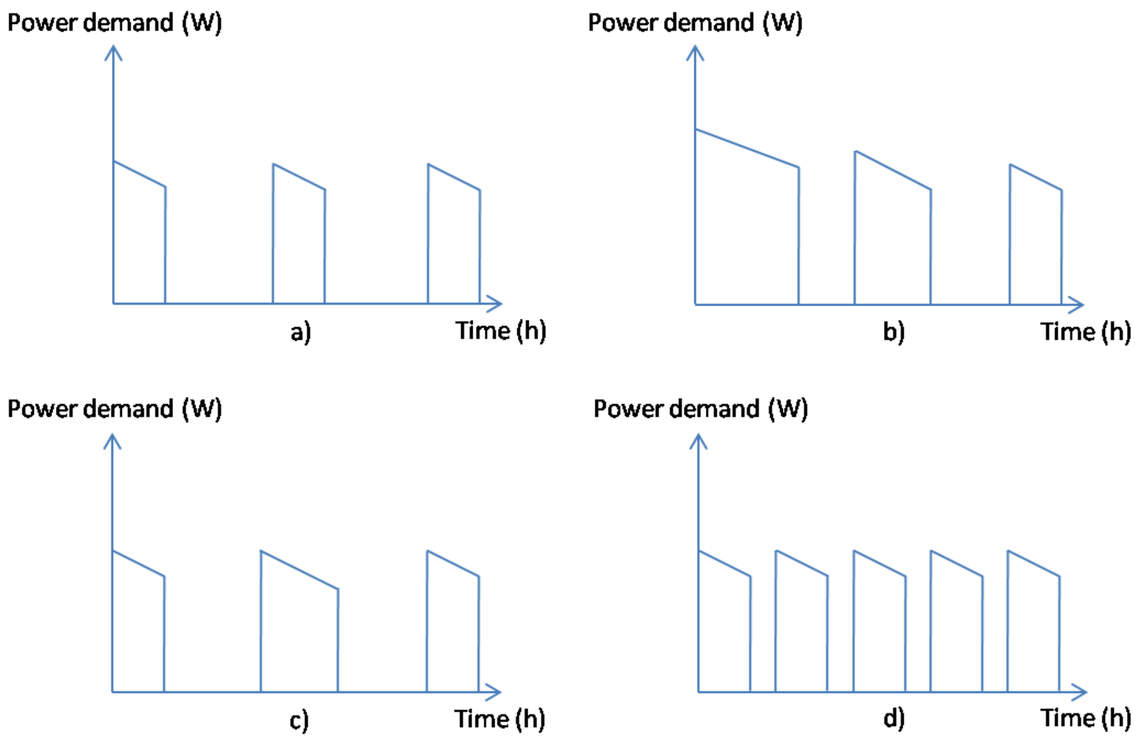


Figure 8 : Unitary load cycles for a fridge

In spite of the real impact of the local temperature[23] on the consumption of a fridge and thus on its power demand, our method doesn't model this influence for the moment because of the lack of sufficient detailed data. However it could be implemented as soon as viable data will be available.

Methodological strategy

As we previously said, we decided to make use of our method on a detailed n-tuple. So let's suppose that the simulated n-tuple's fridge is characterized by the elements contained in the second column of **Error! Reference source not found.**.

The time-series charts for the fridge are given in Figure 9. In this graph, the rectangles indicate the time slots related to the human activities which cause various fridge functioning modes and the steady

[23] temperature of the room where the fridge is placed in

state periods. The weekday sequence begins with a steady state mode which occurs at the night time underlying that there is no event that breaks the normal functioning. Then a large time slot is noticeable[24] as soon as the occupants wake up. Because of their breakfast, there is very chance that the fridge could be opened and closed many times especially if household's members don't wake up simultaneously. Then another steady state starts from 8.30AM up to the middle of the afternoon. Lunch isn't taken at home. The steady state functioning is interrupted at about 4.30PM following the children's afterschool snack. After that another steady state starts which is the piece of evidence that household's members are likely to do domestic activities that don't imply the fridge. Then a long period begins: it is caused by the preparation of the dinner. At the end of the day, another normal functioning occurs.

In the case of the weekend day, the later waking-up of the household's occupants is notable: the corresponding time slot begins at about 8.15PM. Then another longer period in non-steady state functioning mode could be seen around the lunchtime indicating that the occupants eat at home and have to prepare it. This sequence ends at about 2.00PM. Steady state follows this up to about 7.30PM. Here we assume that the children don't take a snack and no interruption occurs during the afternoon. Moreover, it supposes a later dinner time compared with the weekday.

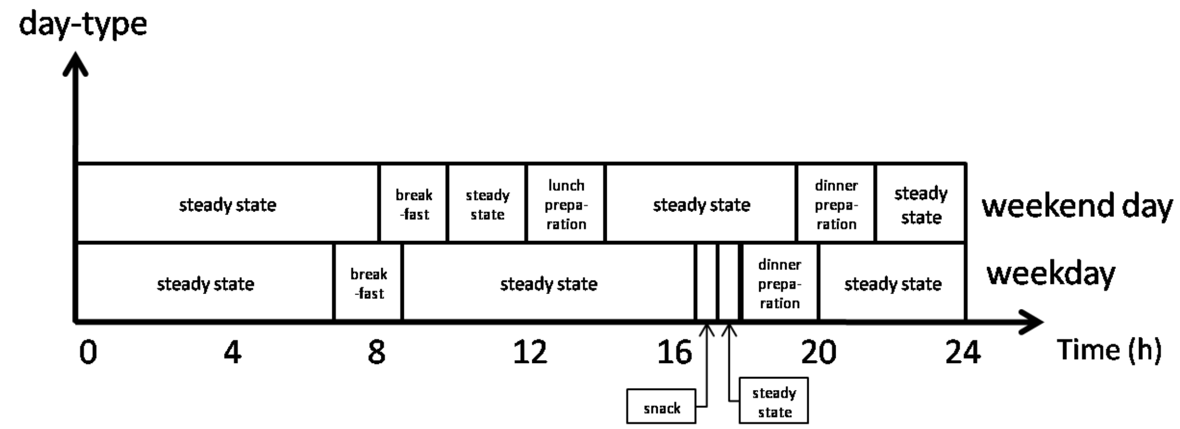


Figure 9 : Fridge time-series charts for the simulated days

Because of the independent functioning of the fridge, the model doesn't need all the switch-on events times throughout the simulated days. Yet according to the previous time-series charts, door openings are distributed in the identified time slots where domestic activities take place. Moreover the model indicates if these events are followed by a restocking (that's not the case here for the two days considered). Thus, the method constructs the Time of Use scenarios which only contain in our case studies the starts times following a door opening. A random delay is added in our model so that each switch-on event after an opening doesn't follow it immediately. The extracted Time of Use scenarios are presented in Table 4.

Table 4 : Time of Use scenarios for the fridge and the simulated days

		Time of the day(h)			
Weekday	AM	6.57	7.20	7.47	8.10
	PM	4.40	6.22	6.50	7.35
Weekend day	AM	8.30	8.50	9.14	9.29
	PM	12.10	12.19	12.43	.1.18

[24] between about 7.00AM and 8.30AM

		1.46	7.35	7.53	8.23

We suppose that the temperature set of the fridge is 4°C. The corresponding load cycles in steady state and these which follow a door opening are available in the data base. So the model chooses the power demand patterns according to the functioning modes and sets them at the identified starts times. This processing gives the load curves for the weekday and the weekend day. Figure 10 shows the schematic appearance of the weekday fridge load curve.

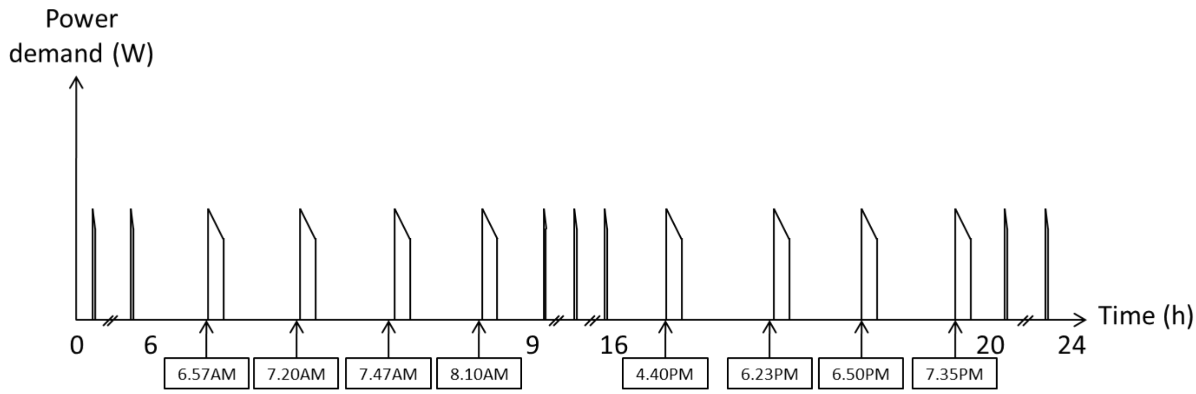


Figure 10 : Fridge load curve for the simulated weekday

Modelling of the washing-machine

Specificities

Washing-machine is an appliance whose functioning is cyclic too. Contrary to the fridge, its running is partly dependent on the human presence and awareness. However, the switch-on events are distributed in a day according to the habits of the households' members. In fact with modern devices, the start of a functioning cycle is programmable so that switch-on at the nighttime is remarkable in certain measure campaigns such as REMODECE[25]. Moreover depending on the selected functioning mode the corresponding power demand duration and magnitude may be notably different.

In Figure 11 we give some illustrative examples of unitary load cycles for a washing-machine. Here again these don't correspond to real measurements that would quite obviously give less smooth load curves. Case a) may correspond to a 60°C washing cycle. Three peaks could be identified: the first one is the power demand for the water heating. The second peak represents the power demand for rinsing. At the end of the unitary load cycle, a third notable power demand peak is caused by the spin-drying phase. Example b) looks like case a) but the power demand magnitude for each peak is lower and the cycle duration is shorter. This unitary load cycle is likely to be a 30 or 40°C washing cycle with a reduced spin speed compared with case a). In the load cycle c), there is no water heating peak what underlines that this could be a cold washing programme. Finally case d) only shows a short power demand which could be the required load pattern of a high-speed spin-drying phase.

Here again with detailed measurements data, it would be possible to link precisely the unitary load cycles with the characteristics of the corresponding washing-machine.

[25] REsidential MOnitoring to Decrease Energy use and Carbon emissions in Europe

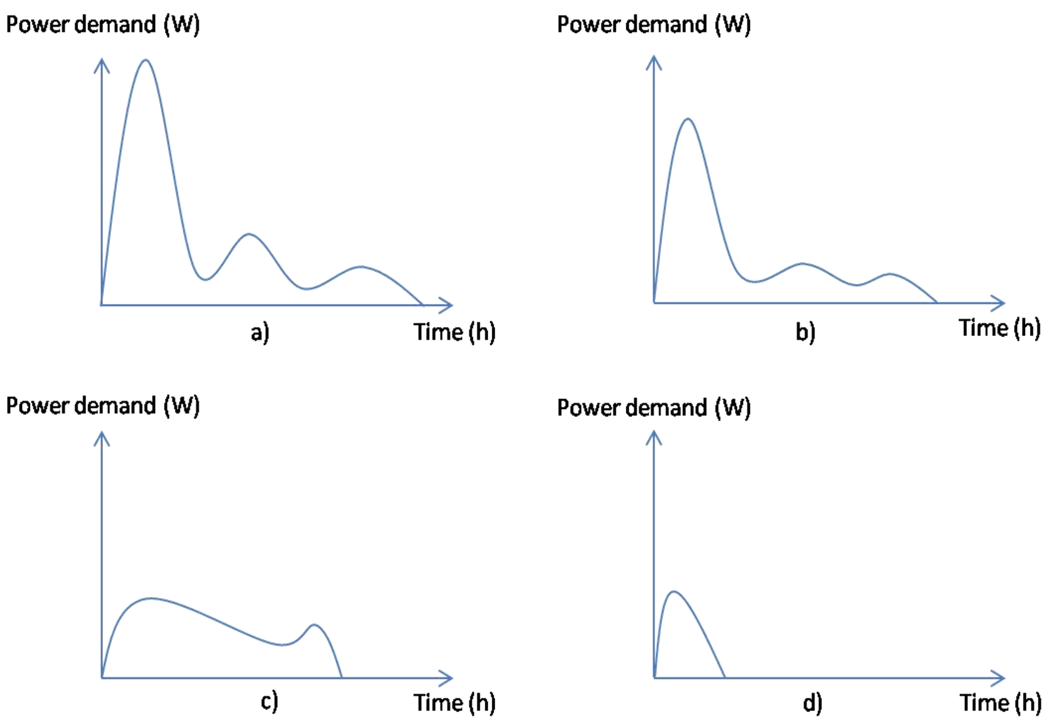


Figure 11 : Unitary load cycles for a washing-machine

Methodological strategy

The simulated n-tuples owns a washing-machine whose characteristics are given in the third column of **Error! Reference source not found.**.

We pass through the methodology for the two days-types. Corresponding times-series use charts are represented in Figure 12.

Figure 12 : Washing-machine time-series charts for the simulated days

We first consider the weekday. Because of the possibility to program this appliance, functioning could happen during the night so that washing could be hung up to dry in the morning. The absence of possible functioning at the beginning of the day indicates that the family isn't prone to let the clothes in a full tub the whole day. A second functioning time slot may occur at the evening as soon as the adults come back home. The switch-on is supposed to happen so that the end of the cycle is attained at 10.00PM (washing must be removed from the device for drying and so requires a human intervention).

The time-series use chart is very different at the weekend because of a more important availability of the household's members which supposes that the occupants stay mainly at home. The functioning time slot only begins at 10.00AM because of a later waking up of the dwelling occupants for this day-type.

We assume that the functioning modes are respectively a 30°C cycle for the weekend and a 60°C at the weekend[26]. Because of an indifferent household's behaviour towards the specific electricity use, there is little chance that the eco mode is selected.

According to these time-series use charts, random starts times for both typical days have been selected so as to get the following Time of Use scenarios[27]:

- weekday: start time at 6.11PM;
- weekend day: start time at 2.28PM.

The model then associates the unitary load cycles on the Time of Use scenarios which give the unitary load curves for the simulated days. These results are represented in Figure 13.

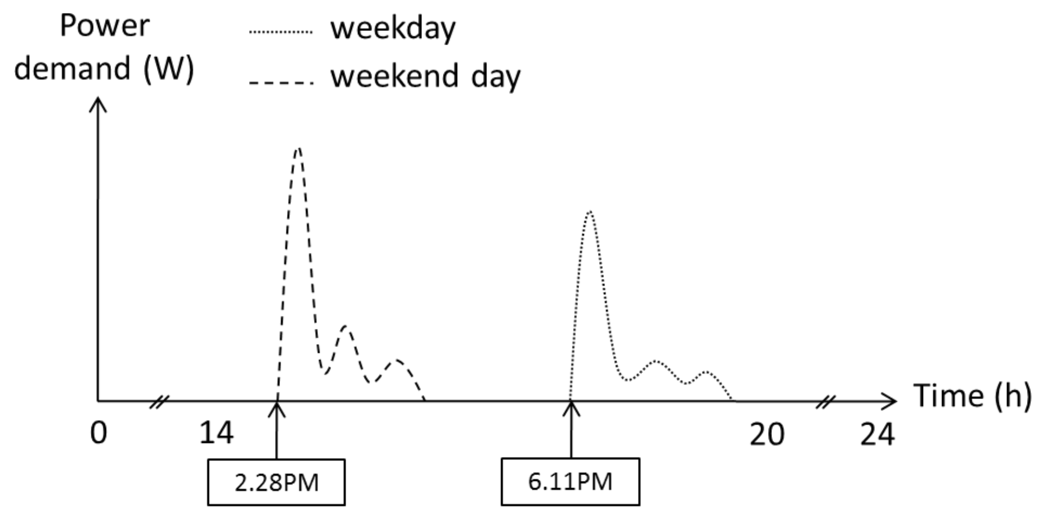


Figure 13 : Washing-machine load curves for the simulated days

Modelling of the lighting

Specificities

This end-use is a little more complicated to simulate than the previous devices because of its more human dependent functioning characteristics. First it is due to its dependence with the natural light availability. Logically lighting is only used when the occupants of a household are present in their dwelling and when the sunlight isn't available. Yet, some exceptions could happen for specific purposes such as night surveillance or lighting use in rooms where the natural light doesn't satisfy the human comfort or simply isn't available at all. In the whole, this end-use is run preferentially before the sunrise and after the sunset when the occupants are awake but the functioning at other daytimes isn't unlikely at all. Moreover lighting is an end-use which implicates several appliances per dwelling: in

[26] the occupants are less constrained at the end of the week in terms of cycle duration – 60°C is supposed to be longer than a 30°C cycle

[27] one cycle is supposed to occur at each of these simulated days according to the weekly number of washing-machine cycles for this n-tuple

fact there are at least so many bulbs and other lighting systems as the number of the rooms in each studied typical building. On top of that, for a selected n-tuple, the set of typical appliances for lighting may be very heterogeneous because of the diversity of these devices which fulfill human and room specific lighting needs.

In Figure 14 we present some schematic unitary load cycles for lighting to an illustrative aim. Case a) shows a short constant power demand whose magnitude could be selected thanks to a regulator. The shape of the power demand may be characteristic of an incandescent light bulb notably with the instantaneous load demand increase. According to the nominal wattage of the light bulb, its power demand is determined and could be significantly more[28] (or less) important than the previous described bulb. Case b) underlines the variability of the power demand duration for the same type of device. Case c) may represent the unitary load cycle for a compact fluorescent lamp whose power demand begins linearly up to its maximal lighting capacity. In case d), though a regular power demand magnitude and duration, the representation focus on the irregularity of the switch-on events. This case may be the load curve which corresponds to a controlled lighting of a room depending on the human presence. For instance, the lighting elements in a corridor or a garden spotlight could be turned-on such a way.

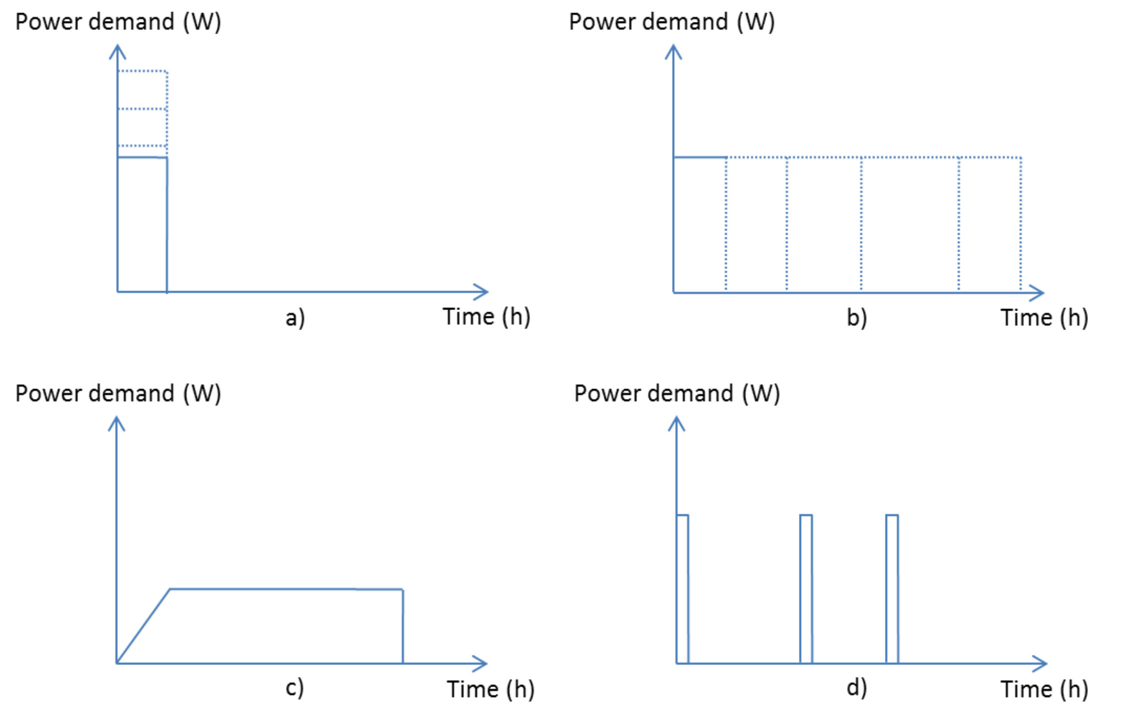


Figure 14 : Unitary load cycles for different lighting related appliances

Methodological strategy

We assume that the n-tuple is only equipped with two kinds of lighting typical appliances whose properties are contained is the two last columns of **Error! Reference source not found.**. According to the lighting needs in each dwelling room that first depends on its surface area, Lb_1 or Lb_2 is chosen by the model.

As lighting use is mainly determined by the human presence and awareness, the model first has to select domestic activities start and stop times (respectively t_{start} and t_{end}) for the considered n-tuple and according to the day-type. These data come from the corresponding density functions included in the definition of the typical days.

[28] in our graph

In accordance with the previous case studies, the model selected the following values:

- weekday: t_{start}=6.55AM and t_{end}=11.23PM;
- weekend day: t_{start}=8.17AM and t_{end}=10.35PM.

We assume that the simulated typical days occur in winter and at these days the natural light when available is systematically too low to satisfy the human lighting needs. These conclusions depend on the position in the year of the regarded days, the corresponding sunrise and sunset times and the geographical zone considered.

The time-series charts for lighting are constructed according to the domestic activities of the n-tuple's members and the corresponding rooms they are supposed to occupy to do these. One passing through the method gives the illustrative time-series charts presented in Figure 15.

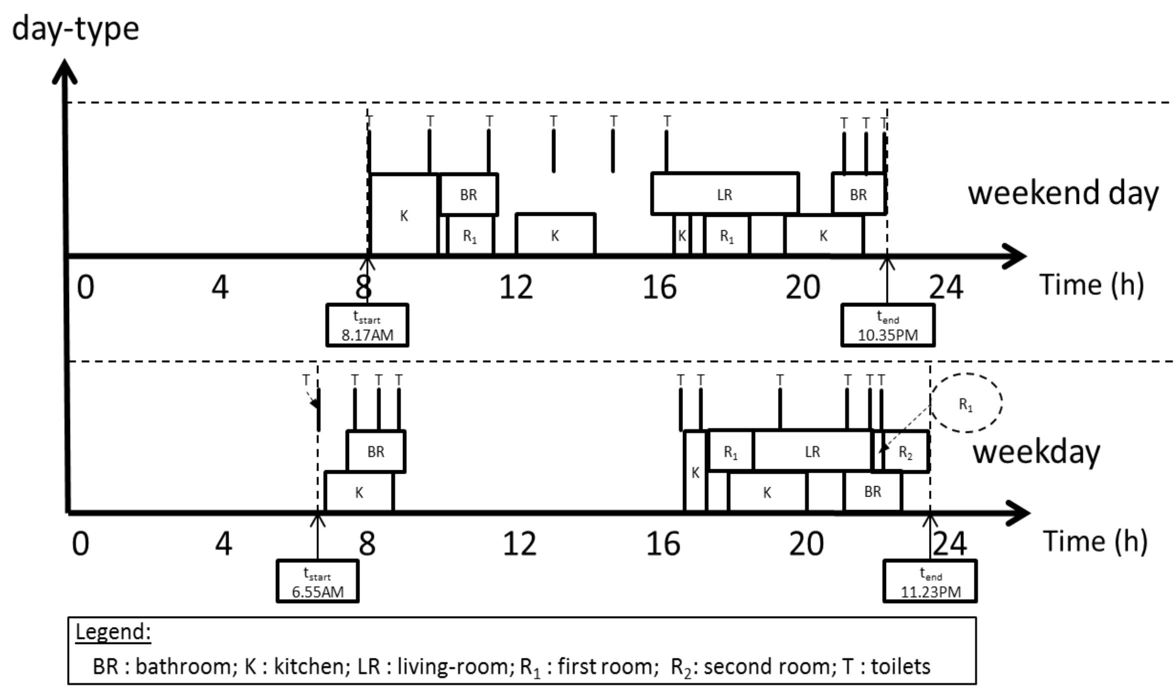


Figure 15 : Lighting time-series charts for the simulated days

We don't comment exhaustively Figure 15 because of its relative simplicity. We only underline the coherence of this data with regard to the two previous case studies. For instance, we could notice at the weekend day that the kitchen is occupied notably from about 12.00PM to about 2.30PM and a short period about 4.30PM. When supposing that the washing-machine is placed in this room, this occupation scenario reveals its whole sense.

Then when first assuming that Lb_1 is only set in the kitchen and in the living-room and Lb_2 is used everywhere else. Secondly we suppose that there is no energy wasting: the n-tuple's members turn the light off when leaving a room. Thirdly in **Error! Reference source not found.**, we can notice that the unitary load cycle for both lighting typical appliances have to be parameterized. the model produces the lighting load curves for both simulated days. Figure 16 represents the obtained lighting load curve for the weekly day-type.

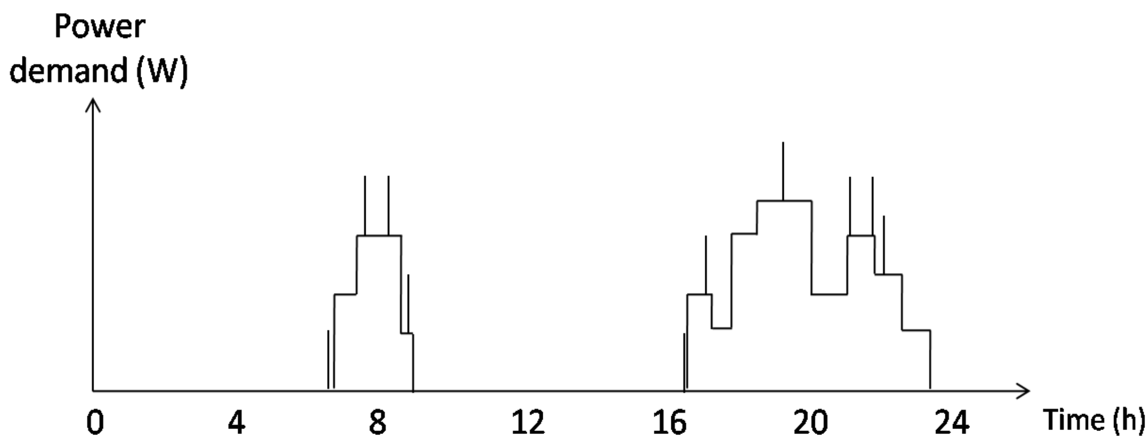


Figure 16 : Lighting load curve for the simulated weekday

Discussion

Our method has been developed so that it could easily evolve according to the simulated inhabited stock and the evolution scenarios that might occur in the future. Concretely it consists in periodic updates which enable a permanent coherent modelling notably in terms of typical elements, affectation laws, input data. The human behaviour modelling plays a great part in our methodology because:

1. it widely influences the domestic electric demand profiles,

2. and deep changes are going to be experienced in a near future concerning the attitude towards energy use.

Thus the capability to take into account a series of representative behaviours and modifications of them seems to us essential to estimate the residential electric power demand.

Yet the model has to be improved in order to take into account influences that are not implemented in this first version (for instance the impact of electricity tariffs on the power demand). That is the reason why we choose to build-up a modular tool. Thus any additional or remote element doesn't change the general architecture of the model. However all the constitutive model parts[29] are standardized: for instance the in- and output data formats of an n-tuple are the same independently of the modalities taking by the considered n-tuple. Scalability, modularity, adaptability[30] and human behaviour modelling are the main strengths of our model. On the opposite, frequently updated extensive input data, detailed knowledge of the residential sector are required. This represents a noticeable weakness and/or difficulty of the exposed methodology.

---

[29] each one could be seen as a box

[30] our method is non specific of a particular inhabited stock

In the case of the electricity specific end-uses, load curves are obtained thanks to various iterative, selection, affectation steps which work with very specific elements[31] and that are precisely arranged in order to take into consideration all the influences affecting the domestic power demand. For the thermic end-uses, the generation of the load curves is a little different because of the required building-simulation software which calculates the heating and cooling needs that depend on the geographical zone considered and thus the corresponding weather data.

So as to build up the required database for the establishment of our model, we make use of various sources of information:

- typical buildings and households are defined notably thanks to dwellings statistical survey on the one hand, population general census on the other hand. In France, both are carried out by the INSEE (Institut National de la Statistique et des Études Économiques);
- data about the inhabited stock in the whole (inclusive energy consumption) are provided by the CEREN (Centre d'Études et de Recherches Économiques sur l'Énergie);
- typical appliances are implemented with help of manufacturers and on-site measurement campaign data such as REMODECE or our own;
- weather data come from hourly readings conducted in stations distributed on the territory. In France the institute is METEO FRANCE.

Conclusion

In this paper, we exposed the domestic end-uses reconstitution load curve model that we established. We first described our method in a global way so as to introduce and define the different elements of the modelling. Then, we chose three electricity specific end-uses (fridge, washing-machine and lighting) and we discussed their main particularities which are the most relevant properties that influence their individual power demand. After that we selected a specified n-tuple and we made use of our method to get daily end-use load curves. We presented some input data as illustrative figures and we graphically plotted the results of our model. At the end of the article, we discuss the improvement possibilities of our method and we shortly underline the load curve calculation procedure in the case of the thermic end-uses.

[31] unitary load cycle, time-series charts, density functions

References

[1] Aigner D.J., Sorooshian C. and Kerwin P. *Conditional demand analysis for estimating residential end-use load profiles*. The Energy Journal, vol. 5 n°3, 1984, pp. 81–97.

[2] Bartels R., Fiebig D.G., Garben M. and Lumsdaime R. *An end-use electricity load simulation model: Delmod*. Utilities Policy, vol. 2, n°1, 1992, pp. 71 – 82.

[3] Yao R. and Steemers K. *A method of formulating energy load profile for domestic buildings in the UK*. Energy and Buildings, vol. 37, n°6, 2005, pp. 663 – 671.

[4] Walker C.F. and Pokoski J. L. *Residential load shape modelling based on customer behaviour*. IEEE Transaction on Power Apparatus and Systems, vol. 104, n°7, 1985, pp. 1703 – 1711.

[5] Capasso A., Grattieri W., Lamedica R. and Prudenzi A. *A bottom-up approach to residential load modelling*. IEEE Transaction on Power Systems, vol. 9, n°2, 1994, pp. 957 – 964.

[6] Widén J., Lundh M., Vassileva I., Dahiquist E., Ellegård K. and Wäckelgård E. *Constructing load profiles for household electricity and hot water from time-use data. Modelling approach and validation*. Energy and Buildings, vol. 41, n°7, 2009, pp. 753 – 768.

[7] Widén J. and Wäckelgård E. *A high-resolution stochastic model of domestic activity patterns and electricity demand*. Applied Energy, vol. 87, n°6, 2009, pp. 1880 – 1892.

[8] Armstrong M.M., Swinton M.C., Ribberink H., Beausoleil-Morrison I. and Millette J. *Synthetically derived profiles for representing occupant-driven electric loads in Canadian housing*. Journal of Building Performance Simulation, vol. 2, n°1, 2009, pp. 15 – 30.

[9] Richardson I., Thomson M., Infield D. and Clifford C. *Domestic electricity use: a high-resolution energy demand model.* Energy and Buildings, vol. 42, n°10, 2010, pp. 1878 – 1887.

[10] Stokes M. *Removing barriers to embedded generation: a fine-grained load model to support low voltage network performance analysis*. Ph.D. thesis. De Montfort University, 2005.

[11] Paatero J. and Lund P. *A model for generating household electricity load profiles*. International Journal of Energy Research, vol. 30, n°5, 2006, pp. 273 – 290.

[12] Train K., Herriges J. and Windle R. *Statistically adjusted engineering models of end use load curves*, Energy, vol. 10, n°10, 1985; pp. 1103 – 1111.

[13] Train K. *An assessment of the accuracy of statistically adjusted engineering (SAE) models of end-use load curves*. Energy, vol. 17, n°7, 1992, pp. 713 – 723.

[14] Hong W.C. *Application of chaotic ant swarm optimization in electric load forecasting*. Energy Policy, vol. 38, n°10, 2010, pp. 5830–5839.

Method for Estimation of Residential Energy Consumption Structure

Yuko Kanamori and Yuzuru Matsuoka

National Institute for Environmental Studies, Kyoto University

Abstract

To overcome the global warming and energy issues, it is very important to grasp energy consumption by energy end-use devices. Focusing on the residential sector, energy consumption structure is very complex, because the structure depends on regional development level, climate characteristics and energy accessibility. If we want to know the detailed structure, detailed residential energy survey is needed. But detailed survey needs enormous effort and cost, so most of detailed surveys are done in some developed countries and we can partly know the structure. In this study, we proposed a method to estimate energy consumption and energy service supply and demand using available statistics and references. This method is useful in following point; it is possible to estimate unknown information which is consistent with energy service supply and demand balance using limited known information. We applied the method to residential sector in world 35 regions, and estimated energy consumption by energy service and fuel type in 2005. The results show that 1) the method could estimate valid energy consumption comparing with Japanese statistics even though the statistics is not used in this method, 2) residential energy consumption in least less-developed countries such as Africa and some Asia countries are mainly for cooking and hot water, and 3) in some rapidly developing countries such as Singapore and Taiwan, residential energy is used not only for cooking and hot water but also for cooling and electric appliances.

Introduction

Ascertaining energy consumption by energy type and service type is important in order to understand and overcome the issues of global warming, energy and resources. In the residential sector in particular, energy is required even for a minimal standard of living, but the structure of that energy consumption is made complex by the economic circumstances of the region in question and its regional characteristics, and understanding it completely is difficult. For example, cooking is an essential energy service in any region regardless of its level of development. In developing regions the traditional biomass serves as a source of energy, while in developed regions gas and electricity are used for cooking. The World Energy Outlook[1] (WEO) sorts these complexities in the residential sector's energy consumption in line with income level differences. The use of energy changes correspondingly with the level of income (development) in the region, and energy-consuming services also change in line with the type of energy available for use.

Particularly in developing countries such as the markedly developing Asian countries, it is predicted that there will be huge increases in energy consumption and sudden changes in the energy consumption structure due to rising populations and economic progress. In thinking about future global warming, energy and resource problems, ascertaining the demand-and-supply structure of energy services is extremely important.

At the present time a number of investigations into energy consumption in the residential sector have been made, but these include research that has been unable to ascertain direct energy consumption, and even in the cases in which it has been ascertained the classifications and subjects of the research vary greatly, making it very difficult to obtain a detailed grasp of worldwide energy consumption in the residential sector. In order to ascertain and analyze on a worldwide basis the precise trends in energy consumption in the residential sector, our research proposes a method for grasping energy consumption by service and energy type with the use of the available data, and shows the results of the application of this method to 35 regions throughout the world for the year 2005.

Energy services demand-and-supply balance

Outline

The relationship indicated in Fig. 1 is established in the energy services demand-and-supply balance. Latent demand for energy services is decided by multiple social factors (such as climate, social issues, culture and so on), which exert an impact on the growth and decline of energy services. However, because of income restrictions and material restrictions (such as inadequate infrastructure) arising from the state of economic development of regions, in some cases the expressed demand can actually be lower than the latent demand. In our research we have set the ratio of latent demand to expressed demand as the expression coefficient. On the other hand, it is the device for supplying energy services and the energy for powering that device that decides the supply of energy services. The energy services demand-and-supply balance represents a sort of relationship in which the volumes of expressed demand and supply match each other.

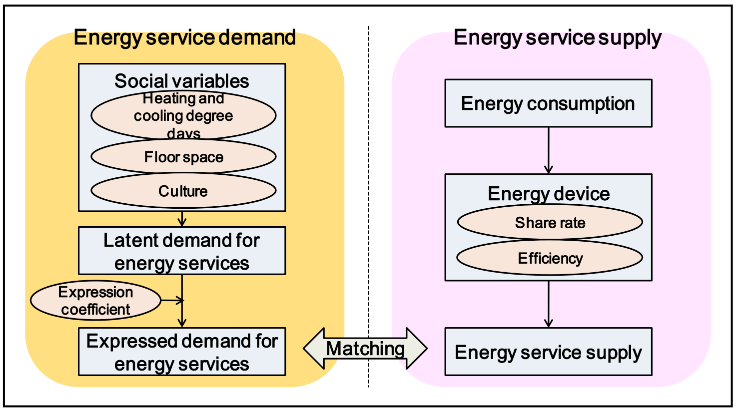


Figure1 Energy services demand-and-supply balance

Formulation

Based on the energy services demand-and-supply balance explained above, we formulated the relationship between energy consumption, expressed demand for energy services and energy device. The variables employed are as shown in the list in Tab. 1. Energy consumption by energy type and energy consumption by service type are in a relationship between expressed energy service demand and energy device shown in equations (1) and (2) below. In other words, multiplying the share rate of device by the energy intensity of device, and then totalizing this in terms of device type gives the average energy intensity of device by service type. And energy consumption by energy type or by service type can be obtained from the average energy intensity of device by service and expressed service demand.

$$E_r^l = \sum_k E_r^{k,l} = \sum_s \left(D_r^s \cdot \sum_{k \in SK(s)} cnv_r^{s,k} \cdot ef_r^{k,l} \right) \tag{1}$$

$$ES_r^s = D_r^s \cdot \sum_l \sum_{k \in SK(s)} \left(cnv_r^{s,k} \cdot ef_r^{k,l} \right) \tag{2}$$

Here the ‘share rate’ of the device is the proportion accounted for by device *k* of an device group *SK(s)* providing a service, and it enjoys the relationship defined below in equation (3):

$$\sum_{k \in SK(s)} cnv_r^{s,k} = 1 \tag{3}$$

Energy intensity is the reciprocal of energy efficiency, and has been set as the energy consumption necessary for providing units of service. In our research it is defined in equation (4) as follows:

$$ef_r^{k,l} = E_r^{k,l} / D_r^{k,l} \tag{4}$$

Estimate method

Outline of estimate method

Based on the demand-and-supply balance of energy services, we developed a method for using the publicly available data to estimate energy consumption and energy service volumes consistent with various information. Fig. 2 shows the flow of the estimate calculations. First of all, the terms used in the research are defined as follows. Due to the way they are treated during the estimates, the data that we have used in this research is classified into three types – assumed values, initial values and estimate values. The assumed values are values obtained prior to making the estimates. The values obtained from statistical publications or configured in some way or another prior to the estimates are also called assumed values. The initial values are the values configured at the start of the estimates.

Table 1 List of variables employed

Symnol	Explanation
s	Service type
l	Energy type
r	Region
k	Device type
SK	Aggregate of device k conducting service s
E_r^l	Energy consumption of region r and energy l
RE_r^l	Proportion of energy consumption of region r and energy l
$E_r^{k,l}$	Energy consumed by region r , device k and energy l
ES_r^s	Energy consumed by region r and service s
RES_r^s	Proportion of energy consumption of region r and service s
D_r^s	Service demand of region r and service s
$D_r^{k,l}$	Service demand covered by region r and device k
$cnv_r^{s,k}$	Share of device k providing region r and service s
$ef_r^{k,l}$	Energy intensity of device k conducting services in region r and energy l
$w1$	Weighting of E_r^l
$w2$	Weighting of ES_r^s
$w3$	Weighting of D_r^s
HDD_r	Heating degree days in region r
CDD_r	Cooling degree days in region r
ARH_r	Per capita heating floor space in region r
ARC_r	Per capita cooling floor space in region r
Q_r	Heat loss coefficients in region r
UCK_r	Cooking intensity in region r
REH_r	Rate of eating at home in region r
PHW_r	Per capita hot water supply demand in region r
GDP_r	Per capita GDP in region r

The estimate values are the values that were arrived at as a result of applying our method. This estimate method is composed of three main steps, the flow of which is explained below.

<u>Step 1: Collection of assumed data prior to calculations</u>

Step 1-1: Collection of assumed values for energy consumption

Data that will serve as assumed data for energy consumption is collated from reports and statistics.

Step 1-2: Estimating the assumed values for expressed service demand

Using the social variables that decide expressed service demand the values that become the assumptions of expressed service demand are estimated.

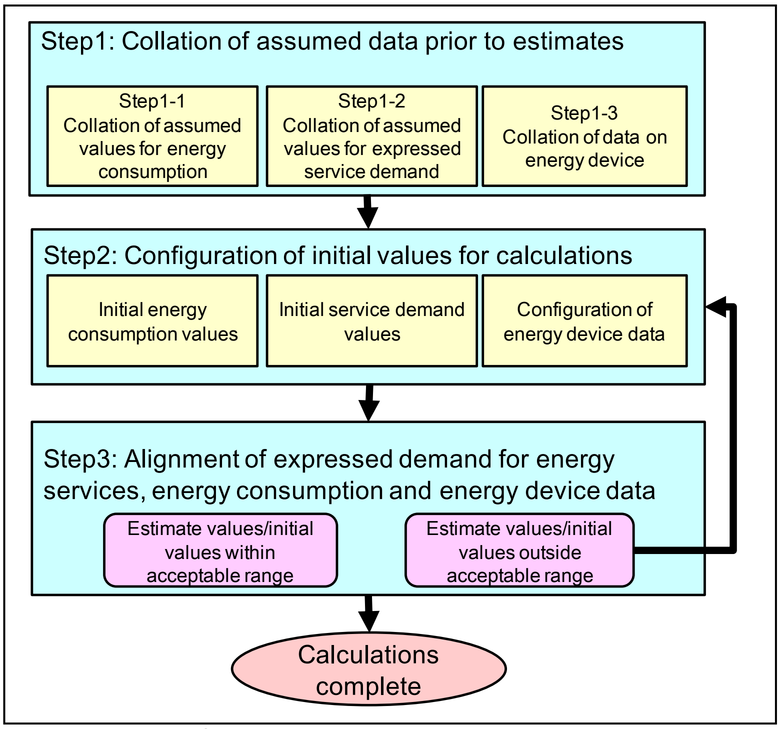


Figure2 Flow of estimates

Step 1-3: Collection of data on energy device

Information about the share rate of energy device and energy intensity is collated. The share rate is made to satisfy the relationship in equation (3). The energy intensity of energy device is configured from information about its energy efficiency.

Step 2: Configuration of initial values for calculations

Based on the assumed values for energy consumption and expressed demand for energy services collated or configured in Step 1, the initial values used in the calculations are configured. At the start, the assumed values are used as initial values.

Step 3: Alignment of expressed demand for energy services, energy consumption and energy device data

In order to achieve consistency between the expressed demand for energy services, energy consumption and energy device data, the expressed energy service demand and energy consumption are calculated. The estimate values and initial values are compared, and if the difference between them is within an acceptable range the estimates can be considered concluded. In the event that there are major discrepancies between the estimate values and initial values, you have to go back to Step 2 and revise the initial values or share rate of the device, and re-calculate the estimates. This process must be repeated until a difference between the estimate values and initial values that is within an acceptable range is obtained.

Regarding the configuration of variable classification

Our estimates estimated the demand-and-supply structure for energy services in the year 2005. The world was divided into 35 regions, and eight types of energy and five types of services were configured. The details of each configuration are shown in Tabs. 2 to 4. The ‘biomass’ category in the energy types refers to traditional biomass.

Table 2 Regional classifications

15 Asian regions		Other 20 regions			
JPN	Japan	XME	Middle east	ARG	Argentina
CHN	China	TUR	Turkey	MEX	Mexico
IND	India	AUS	Australia	XLM	Other Latin American
IDN	Indonesia	NZL	New Zealand	ZAF	South Africa
KOR	South Korea	CAN	Canada	XAF	Other African
THA	Thailand	USA	The United States		
TWN	Taiwan	XE15	Western Europe (EU member states)		
VNM	Vietnam	XE10	Eastern Europe (EU member states)		
MYS	Malaysia	XE2	Bulgaria and Romania		
PHL	The Philippines	RUS	Russia		
SGP	Singapore	XCS	Central Asia ("stan" countries)		
XSE	Other south-east asian	XEWI	Other Western European (Annex I)		
XSA	Other south asian	XEEI	Other Eastern European (Annex I)		
XEA	Other east asian	XENI	Other European		
XOC	Other oceanian	BRA	Brazil		

Table 3 Energy classifications

Biomass (BM)	Kerosene (OK)	Natural gas (NG)	Heat (HT)
Coal (CL)	LPG (OL)	Electricity (EL)	Solar thermal (ST)

Table 4 Service classifications

Service type	Definition
Heating	Heating living space. Includes heating of whole buildings and rooms, and keeping the body warm by heaters etc.
Cooling	Cooling living spaces. In our research this covers only the use of air conditioners to reduce temperatures throughout rooms.
Hot water supply	Boiling hot water for use.
Cooking	Cooking food.
Other	Energy service not included in the above. Typical examples would be lighting, refrigerators, televisons and so on.

Collection of energy consumption by energy type (Step 1-1)

The assumed values for energy consumption used values adjusted from the energy balance table[2,3] using the methodology of Fujimori et al.[4] Fujimori et al.[4] conducted an adjusted calculation using social and economic variables that can influence the energy consumption of each sector, because i) the IEA data is discontinuous with regard to locations other than where there may be sudden changes in energy consumption due to political change or oil crises, and ii) because in the IEA table energy consumption that could not be properly classified due to a lack of information is allocated as 'non-specified.' As a result, energy consumption is estimated with an alleviation of the problems of discontinuance and the 'non-specified' issue.

Collection of energy consumption by service type (Step 1-1)

The assumed values for energy consumption by service type use research results and statistics in the regions where they are available[5, 6, 7, 8, 9, 10, 11], and SAGE[12] data where they are not. In this paper, from a perspective of easily coordinating the data we configured detailed region-specific energy consumption by service type for seven regions. SAGE[12] values were used for the remaining regions. The question of how we can use region-specific report data to configure assumed values, which we were unable to do this time, is an issue that will need to be addressed in the future.

Estimation of assumed values for expressed demand for energy services (Step1-2)

Energy service demand is split into two categories, latent and expressed demand. Latent service demand has the relationship with social variables shown in the equations (5) to (9), and their configuration is as shown in Tab. 5. In our research per-capita expressed service demand in regions was configured when the per-capita expressed demand in Japan is taken to be '1.'

Table 5 Method for configuring variables

Variable	Configuration method
Heating degree days	Heating degree days were aggregated by region at a standard temperature of 18 °C in line with Mitchell, T.D. and Jones, P.D[1].
Per-capita heating floor space	Configured by region based on floor space data in the Encyclopedia Britannica.[2] In regions where a single heating unit is used to heat the entire building the per-capita residential floor space was used as the heating floor space, and in regions with individual room heating the heating floor space was the per-capita average room floor space.
Per-capita cooling floor space	Configured by region based on floor space data in the Encyclopedia Britannica.[2] The cooling floor space was the per-capita average room floor space.
Heat loss coefficients	Configured according to regional climate with reference to the standards in Japan, the U.S., Canada, the UK, France, Germany and Northern Europe.
Cooling degree days	Aggregated by region at a standard temperature of 18°C with the same method used for heating degree days.
Per-capita hot water use	We assumed that the main purpose for hot water in each region was bathing, and configured the variables by region according to bath type and frequency of use.
Rate of eating at home	1 - the eating outside rate. Using Euromonitor International's consumer expenditure data[3] we calculated the proportion of food expenses accounted for by expenses for eating outside of the home.
Cooking intensity	The cooking intensity of Japan was taken to represent '1' and the intensity for other regions configured accordingly.
Per-capita GDP	We used the UN deflator[4] to convert nominal per-capita GDP estimated by Fujimori et al[5] to real GDP (PPP).

1 Mitchell, T. D., and P. D. Jones. *An Improved Method of Constructing a Database of Monthly Climate Observations and Associated High-resolution Grids*. Int. J. Climatol., 25(6), pp693-712, doi:10.1002/joc.1181, 2005.

2 Encyclopedia Britannica. *Britannica Book of the Year 2000, Events of 2007*. Encyclopedia Britannica Inc., 2000.

3 http://www.euromonitor.com/

4 United Nations. *National Accounts Main Aggregates Database*. New York, USA, 2008.

5 Fujimori, S., Matsuoka, Y. *Integration of Energy and Economic Statistics and Estimation of Global Fossil-Energy Consumption and CO2 Emissions Arising from Fossil Fuels*. Selected Papers on Environmental Systems Research, 36, pp37-48, 2008.

Heating demand is taken as being decided by heating floor space, heating degree days and heat loss coefficients.

$$D_r^{"WM"} = ARH_r \cdot HDD_r \cdot Q_r / \left(ARH_{"JPN"} \cdot HDD_{"JPN"} \cdot Q_{"JPN"} \right) \quad (5)$$

Cooling is decided by cooling floor space, cooling degree days and heat loss coefficients, and latent demand is expressed as in equation (6).

$$D_r^{"CL"} = ARC_r \cdot CDD_r \cdot Q_r / \left(ARC_{"JPN"} \cdot CDD_{"JPN"} \cdot Q_{"JPN"} \right) \quad (6)$$

Equation (7) is the relationship between cooking demand and cooking intensity and rate of eating at home.

$$D_r^{"CK"} = UCK_r \cdot REH_r / \left(UCK_{"JPN"} \cdot REH_{"JPN"}\right) \tag{7}$$

Equation (8) is envisaged between hot water supply demand and per-capita service demand.

$$D_r^{"HW"} = PHW_r / PHW_{"JPN"} \tag{8}$$

Other demand includes lighting, televisions, refrigerators and various other services such as household electrical appliances. In these other demands, it is not really possible to separate latent and expressed demand because hitherto unexpected demand arises as disposable income increases. In our research we take per-capita GDP as explaining other demand (equation (9)).

$$D_r^{"OT"} = GDP_r / GDP_{"JPN"} \tag{9}$$

Next, in order to configure the assumed values for expressed demand we configure the expression coefficients shown in Tab. 6.

Table 6 Configuration of expression coefficients

Service type	Method for configuring expression coefficients
Heating and Cooking	Expression coefficient was taken to be 1 as heating and cooking can be provided by the comparatively cheaply available biomass.
Cooling	We considered that the expression coefficients depend on the prevalence of air conditioners.
Hot water supply	We considered that the expression coefficients depend on the volume of water available for use.
Others	Since dividing latent and expressed demand is not a realistic proposal the expression coefficients were taken to be '1'.

Collection of variables regarding energy device (Step 1-3)

In our research, we configured 41 types of energy device. As a rule, we configure the device by service type and energy type into two kinds according to energy intensity. We assumed that the device with low energy intensity was used in developed countries and the device with high energy intensity in developing countries. We now explain the collection of data on device share rate and energy intensity.

Configuration of energy device's share rate

With regard to the energy device's share rate, we used the share rate by service for each country where obtainable.[11, 13, 14, 15, 16] For the regions in which this data was not obtainable we took into consideration the data on the prevalence of device and social and economic circumstances, and used values from neighboring regions to configure them.

Energy intensity of energy device

The information on energy intensity in Japan was obtained from the Energy Conservation Center, Japan (ECCJ)[17]. However, since this information concerns the energy intensity of the very latest device on sale (their energy efficiency being the directly obtainable information), it is expected that their energy intensity is smaller than the average energy intensity of device actually being used. In our research, we took into account the average lifetime of device and configured the energy intensity of device sold in the year 2000 as the average value for energy intensity of device used in 2005. Because the performance of the Japanese device is generally good and its energy intensity lower than that of other regions, we configured the energy intensity of device in other regions as detailed below.

In the case of developed countries

The performance of device in developed countries is generally good, and we assumed that device with similar energy intensity to those in Japan was being used. However, since there are reports that the electrical device outside of Japan displays a slightly higher energy intensity[18], we made the configurations allow for a 10% higher energy intensity in electrical device.

In the case of developing countries

We considered that in the developing countries the energy intensity of the fossil fuel based device used there is higher than the device used in Japan, and made the configurations allow for a 10% higher energy intensity than that of the developed countries. With regard to electrical device, we configured an energy intensity of 30% more for air conditioners[18], but 30% less for device supplying other services. As we have already mentioned, as far as other demand is concerned the introduction of lighting, refrigerators, televisions and so on progresses in line with the development of the region. With regard to device supplying other services, the configuration above has been used because only the energy intensity of lighting is lower than that of the average energy intensity of miscellaneous electrical device.

Configuration of the initial values for estimates (Step 2)

To start with, the energy consumption, expressed demand for energy services and information about energy device were configured as initial values. When it was judged from the results of the calculations shown in Step 3 that the configuration of the initial values was unsuitable, they were revised to more appropriate initial values.

Alignment of expressed demand for energy services, energy consumption and energy device data (Step 3)

Since there is a degree of error in the initial values for the energy consumption and expressed demand for energy services configured in Step 2, it is highly likely that they do not satisfy the relationship between variables shown in equations (1) to (4). So in Step 3 values that simultaneously satisfy equations (1) to (4) are estimated. In doing so the following rules are set.

1) The only three variables moved are proportion of energy consumption by energy type, the proportion of energy consumption by energy service and the expressed demand for energy services.
2) The total value for energy consumption ($= \sum_l E_r^l = \sum_s ES_r^s$) is fixed.
3) When there are multiple solutions simultaneously satisfying equations (1) to (4), the values that minimize the weighted sum of the degree of error in the estimate values and initial values shown in equation (10) are regarded as the final solution.

$$w1 \cdot \left\{ \left(E_r^l \Big/ \sum_l E_r^l \right) - \left(\overline{E}_r^l \Big/ \sum_l E_r^l \right) \right\}^2 + w2 \cdot \left\{ \left(ES_r^s \Big/ \sum_l ES_r^s \right) - \left(\overline{ES}_r^s \Big/ \sum_l ES_r^s \right) \right\}^2 + w3 \cdot \left(D_r^s - \overline{D}_r^s \right)_2 \quad (10)$$

The GAMS 22.6 CONOPT solver was used to obtain the solution in Step 3.

Here *w*1 to *w*3 are the weightings for each variable, and they were estimated as *w*1=5, *w*2=2 and *w*3=1. After obtaining the results of the estimate, the estimates were considered complete when all of the following three conditions regarding the estimate values were satisfied. The degree of error here means the difference between the estimate values and the initial values.

- Of the initial values for proportion of energy consumption by energy type, a 2% degree of error with regard to energy types with an initial value of 5% or above.

-Of the initial values for proportion of energy consumption by energy service, a 5% degree of error with regard to service types with an initial value of 5% or above.

- When the initial values for expressed service demand are 0.5 or more, the ratio of the estimate values and the initial values is between 0.67 or more and 1.5 or less. When the initial values are 0.2

or more and less than 0.5, the ratio of the estimate values and the initial values is between 0.5 or more and 2.0 or less.

In the event that the estimate values do not meet these conditions, we went back to Step 2 and repeatedly reconfigured the initial values for the proportion of energy consumption by service type, expressed service demand and share ratio of energy device until the three conditions above were satisfied.

Results and observations

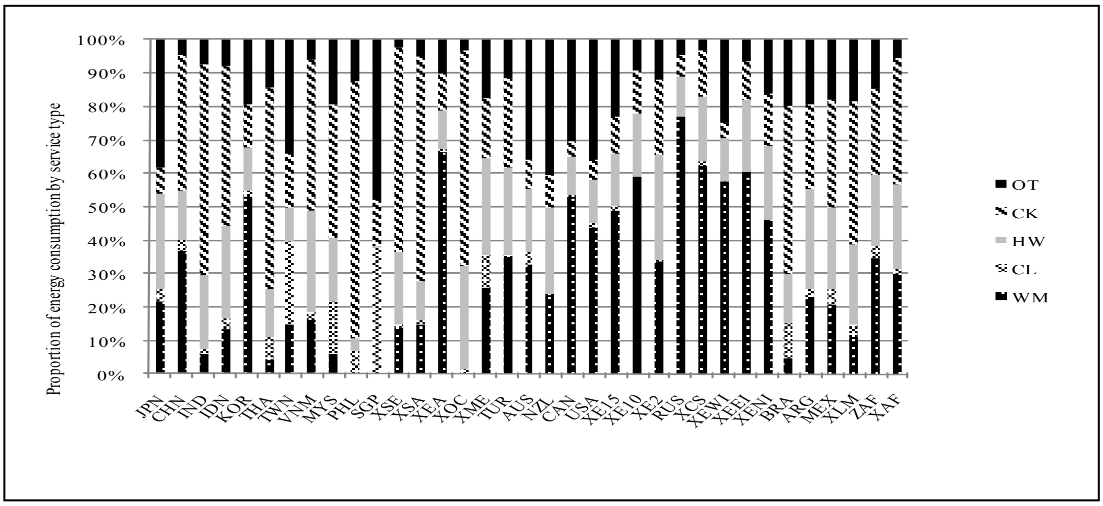
Energy consumption by energy type

In the case of the estimates for energy consumption by energy type, there was hardly any disparity with the initial values for energy consumption by energy type due to their being weighted.

Energy consumption by service type

The results of the estimates for energy consumption by service type are shown in Fig. 3. A look at energy consumption by service type shows that in Canada, Northern Europe and Russia around 60% of total energy consumption is accounted for by heating. This is because in these regions the heating period is long, a single unit is used to heat the entire building, air conditioners are not used and the device that is used has a high energy intensity. Cooling, on the other hand, is provided by electricity, and due to the small size of the energy intensity involved and limitations on the prevalence of this device it accounts for only 10% of consumption in most regions. The comparatively high share of energy consumption that cooling accounts for in Singapore and Taiwan, around 30%, is a feature peculiar to those regions. The results show that since cooking and hot water supply are essential services in any region, even in regions where the proportion of consumption of energy accounted for by these purposes is small it still amounts to about 20%, while in the developing countries accounts for about 80% of consumption. In the developed and newly industrialized countries around 20% to 35% of energy is consumed for other services. In Singapore in particular, around 50% is used for other services.

Expressed service demand



The results of the estimates for expressed service demand are shown in Figs. 4. The values are for when per-capita expressed demand in Japan are taken to be ‘1.’

Expressed demand for heating services was shown to vary tremendously from region to region. As can be seen, in Canada, Northern Europe and Russia, the per-capita expressed demand for services

Figure 3 Proportion of energy consumption by service type

is around six times that of Japan, while demand is four times as large in the U.S., and nearly three times as large in Europe. In South Korea too, demand is also nearly double that of Japan. The regions with similar levels of demand to Japan are Australia, New Zealand, Bulgaria, Romania, and the European regions on similar latitudes to Japan.

Latent demand for cooling services are essential in Asia, Africa, and Central and Southern America, but most of these regions are developing regions and the expressed demand for services is only around half of that in Japan due to the fact that air conditioners are not widely used. On the other hand, the estimates showed that per-capita expressed demand for cooling in the comparatively developed regions of Singapore and Taiwan is between 2.5 to 3 times the levels in Japan. It can be seen that hardly any regions displayed a higher expressed demand than Japan, with demand in the U.S. and Australia being only around 75% of Japan's. It should be noted that our research used the cooling and heating degree days shown in Tab. 5 as the hypothetical values for deciding latent demand for cooling and heating. The standard temperature for all data is 18°C, and a comparison with the actual heating and cooling setting temperatures suggests that, particularly with regard to cooling, the standard temperature is somewhat low. Although the hypothetic values for expressed service demand were adjusted when the estimates were made, it is possible that the estimate results were over-estimated because we calculated them in a manner assuring the smallest possible degree of error with the hypothetic values.

With regard to hot water supply services, expressed demand is high in most of the developed countries and it is clear that it is the developed countries that account for the bulk of expressed demand for hot water supply. The next highest are the Eastern European and Middle Eastern regions, which display an expressed demand for hot water supply services of around 70% of the developed countries' demand. We think that the reasons for the low demand in regions where expressed service demand is half or less than half of that in the developed countries are i) cultural differences in the amount of hot water supply used for bathing, which is the main purpose of heating water, and ii) the cultural and social reason that since these regions are hot, hot water supply is not used for bathing.

The estimates show that in the majority of regions there is more expressed service demand for cooking than there is in Japan. Considering that the rate at which people eat outside of the home in Japan is high, and the fact that in Japan meals are increasingly prepared using simple cooking devices such as microwave ovens, it is to be expected that expressed demand in developing countries of Asia and other regions is nearly 50% higher. On the other hand, the fact that other developed countries also have an expressed service demand of between 1.5 to 2 times that of Japan could well be due to over estimation, and arriving at a suitable method for configuring the initial values for expressed service demand is an issue that will have to be looked at in the future.

The estimates showed that expressed demand for other services was around double that of Japan in Canada and the U.S. The other services category includes numerous services, and configuring average energy intensity for energy device was extremely difficult. It is probably worth examining the possibilities that expressed demand for services in these regions is greater, and energy intensity is far greater, than in Japan.

The estimates also show that every type of expressed energy service is dramatically low in North Korea and Mongolia (XEA). While it is expected that demand for cooling and other services should be rather small, the result that expressed demand for heating and cooking is only around 10% of Japan's is of a level below that required for people to enjoy even the minimum living conditions. With regard to XEA it was not possible to satisfy the conditions of the estimate results unless the final initial values for expressed demand for services were configured at a much lower level than the initial values that were configured at the outset. This is because the total values for energy consumption in this method are configured as being fixed, or in other words the total values for consumption are clearly erroneous.

Conclusions

Our research used the limited publicly available data to develop a method to ascertain the demand-and-supply structure of energy, which was applied to 35 regions across the world for the year 2005. About the method, the following three characteristics can be suggested in conclusion.

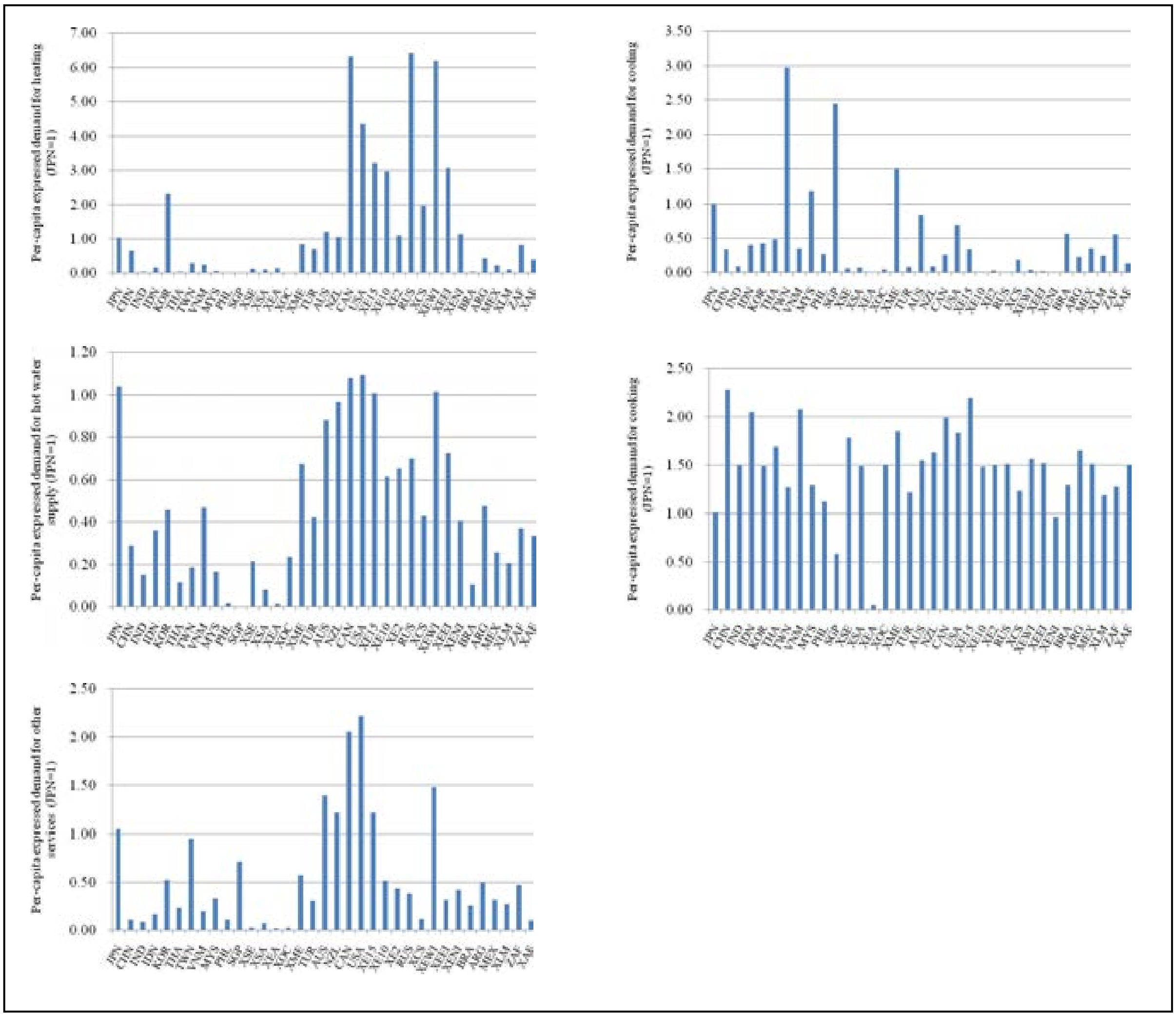


Figure 4 Per-capita expressed demand (a, upper left) heating, (b, upper right) cooling, (c, middle left) hot water supply, (d, middle right) cooking, (e, left below) other)

- This method is useful in ascertaining consistent and hitherto unknown information about the demand-and-supply balance of energy services, using limited data.
- With regard to the fact that the results of our research are consistent with the demand-and-supply balance of energy services, in comparison to the reported values our estimates can be described as displaying a similar or superior precision.
- However, because we have estimated unknown information that cannot be grasped by a method confirming only the consistency that should exist between information sets, we cannot currently verify the reliability of estimate results for which there are no subjects of comparison.

We learnt the following from the results of the estimates.

Using the method, we get the following characteristics in residential energy consumption structure.

- In the developing countries the proportion of energy consumption accounted for by cooking is high, and in some countries it consumes around 60% of energy.

- In the developed countries the proportion of energy consumption accounted for by heating is extremely high in North America and the European countries situated in comparatively high latitudes. In Japan, Australia and New Zealand, energy consumption arising from others, heating and hot water supply is comparatively high.

- Expressed demand for services such as heating and cooling varies according to the format through which they are provided and the region, and the scale of expressed demand differ greatly from region to region due to social and economic restrictions.

References

[1] International Energy Agency. *World Energy Outlook 2002*. OECD/IEA, 2002.

[2] International Energy Agency. *Energy Balances of OECD countries 1960-2005*. OECD, 2007.

[3] International Energy Agency. *Energy Balances of Non-OECD countries 1971-2005*. OECD, 2007.

[4] Fujimori, S., Matsuoka, Y. *Development and Use of an Estimation Method for Energy Input-output Tables Taking into Consideration Energy Conversion Efficiency*. Journal of Global Environment Engineering, 17, pp163-174, 2009.

[5] The Institute of Energy Economics, Japan. *Handbook of Energy & Economic Statistics in Japan*. Energy Conservation Center, Japan (ECCJ), 2009.

[6] Energy Information Administration. *Residential Energy consumption survey*. 2001.

[7] Natural Resource Canada. *Energy Use Data Handbook Tables*. 2006.

[8] Australian Greenhouse Office. Australian *Residential Building Sector for Greenhouse Gas Emissions 1990-2010*. 1999.

[9] http://www.odyssee-indicators.org/

[10] Research Committee of Architectural Institute of Japan. *Study of Energy Consumption and Indoor Environment Problems of Residential Buildings in China*. Architectural Institute of Japan, 2005.

[11] Tata Energy Research Institute. *Teri Energy Data Directory & Yearbook 2000/2001*. Tata Energy Research Institute, 2000.

[12] U.S. Department of Energy. *Model Documentation Report: System for the Analysis of Global Energy Markets (SAGE)*. 2003.

[13] Natural Resource Canada. *2003 Survey of Household Energy Use (SHEU) Detailed Statistical Report*. 2006.

[14] U. S. Department of Housing and Urban Development and U. S. Census Bureau. *American Housing Survey for the United States*: 2005. 2006.

[15] Jyukankyo Research Institute Inc. *2004 Report on Research into Worldwide Lifestyles and Energy*. 2005.

[16] Urban Life Research Institute. *Worldwide Heating 1 (Europe and South Korea)*. Urban Lifestyles Report No. 28, 1993.

[17] http://www.eccj.or.jp/

[18] The Energy Conservation Center, Japan. *Research into the Energy Consumption Efficiency Distribution of Device in Japan and Overseas, and a Comparison of their Efficiency Based on Actual Measurements*. 2004.

Reflections on Chinese household energy consumption based on an analysis of a national survey in Australia

Zhan Yang[1], Sonia Graham[2], Tira Foran[2], Masaya Okumiya[1]
[1] Graduate School of Environmental Studies, Nagoya University, Japan
[2] CSIRO Ecosystem Sciences, Canberra, Australia

Abstract

In recent years it has become clear that the energy consumption in residential buildings in China is increasing very quickly. In order to project the likely residential energy growth in China that will result from rapid economic development, some experience and evidence can be found from the current situation in developed countries. In this paper the analysis is based on a national survey in Australia. The authors focus on the influencing factors and aim to find out how income acts as a driving force for high energy consumption.

Rather than correlating energy consumption and income directly, the authors first try to analyze all the available influencing factors. These include demographic factors, such as income and family size, and building characteristics, such as floor area and insulation. By using cluster analysis and Chi-square tests, it is found that in Australia the family size is the most significant factor for high energy consumption in the household. Furthermore, all the factors showing significant differences in energy consumption are related to family size. After eliminating the influence of family size, the relationship between income and energy consumption is discussed in this paper. Energy consumption increases with income up to a certain income level, then stabilises.

Based on the income-energy consumption curve and the purchasing power parity per capital the discussion points out that the potential for energy consumption to increase in China is great. Some options for energy conservation are provided.

1. Introduction

For most countries residential energy consumption (REC) usually accounts for an important part of the total final energy consumption (IEA, 2005). In China, since the policy of reformation and opening began in 1978, rapid economic growth has been witnessed and inevitably resulted in great increasing energy consumption across all sectors. In 2003, the residential building sector consumed 192.69 million tons of standard coal, which accounted for the second largest proportion (11.3%) of national end-use energy consumption, ranking second only after the industry sector [1].

During the last several decades, a lot of research has been conducted in developed countries regarding the factors that influence residential energy consumption. This research mainly focuses on two main methodologies including nation- wide statistical analysis and modeling. For example, Reinders et al. analyzed the direct and indirect household energy consumption in 11 European countries and found the linear relationship between energy consumption and expenditure. [2] For projecting the long-term energy consumption, a top – down approach is usually applied, combining consumption growth with GDP growth. The IEA report [3] did a detailed study on the OECD countries for such projection of national energy consumption. On the contrary, McNeil and Letschert [4], Department of the Environment, Water, Heritage and the Arts (DEWHA) in Australia [5] used a bottom – up approach to build the residential energy consumption model, by focusing on the individual appliances such as television, washing machines and so on. Lenzen et al. used an input – output model doing a comparative evaluation of the energy requirements for different countries. The results show that energy needs are quite different among those countries and do not support the Kuznets curve. [6]

In recent years, with the rapid economic growth in developing countries, energy and environmental problems in these countries have come into sharp focus and have drawn great attention for research. Jorge and David [7] conducted a study on the trends in Mexican residential energy use between 1984 and 2006. The methodology based on energy end-uses showed that cooking is the main end use, while water heating and appliances are the end uses with the greatest rates of growth. Pachauri and Jiang [8] analyzed the household energy transition in India and China, pointing out that trends in energy use and the factors influencing a transition to modern energy in both India and China are similar. However, due to lack of access to electricity in India (?), the residential energy consumption in China is twice that of India. Joseph Lam did a regression and correlation analysis to investigate the relationship between the residential energy consumption and the demographic and climatic factors. The results show that the yearly electricity use in the residential sector can be estimated based on household income, household size, electricity price and cooling degree days and seasonal variation can be mostly explained by cooling degree days [9]. H.Yoshino did an investigation about the indoor thermal environment of urban residential buildings in five main cities in China. Research from a macroeconomic perspective using the statistic GDP and energy consumption data found that income is the key factor for the increasing residential energy consumption in China. [10, 11]

Influencing factors such as income and population have been indentified to be vital for residential energy consumption in China. However, this research is mostly focused on city or national level, without going into detail about the household level due to lack of detailed investigation. On the other hand, in the developed countries, such research based on detailed questionnaire or monitoring data are available. As China's economic development is following a similar path to developed countries, it is reasonable to project and discuss those REC influencing factors from the current situation of developed countries. In this paper, the authors analyze the residential energy consumption in Australia based on a national wide questionnaire taken in 2009. The influencing factors evaluated for high energy consumption households include floor area and demographic factors such as family size, income, age and so on. It is found that the family size (number of family members) is the most influencial factor rather than income.

Furthermore, a big size family is usually accompanied with more working members which will result in more income. When the factors of big family size and high income appear at the same time in a high energy consumption household, it is necessary to go into detail to find out which is the driving force. In this paper, separating the influence of family size and income is considered. The curve of household income per capita against energy consumption per capita is made. From the literature review and limited report on the internet, the current relationship between residential energy consumption and the income is studied. The discussion in carried out for projecting the potential of energy growth in China, based on the tendency inferred from the curve and comparing of the purchasing power parity (PPP) per capital.

2. Influencing factors of residential energy consumption in Australia

2.1 Basic result of the survey

2.1.1 Background

In Australia, a national survey called "Lifestyles, consumption and environmental impact: National Household Consumption Survey" was carried out by CSIRO (Commonwealth Scientific and Industrial Research Organization). This survey was conducted via internet in 2009 and 2171 people answered the questionnaire about their lifestyle and energy consumption. Since the survey was done through the internet, it is very important to note that there is some bias on the socio-economic characteristics of respondents. Compared to the Australian population, respondents tended to be younger, have higher incomes and have spent more time in tertiary education. [12]

2.1.2 Basic household information based on the survey

- House style. Australia is a country with a large area but small population. It is common for people there to own a house with a yard. The proportion of families living in separate houses (including semi-detached) accounts for about 82% of all the respondent families.
- Family size. The average number of people living in the family is 2.7.
- House area. Based on this research, the average floor area for a house is 144m^2, and the average block area is 670m^2. From this information it can be inferred that in Australia most of the families living in separate or semi-detached houses have a big yard or garden.

2.2 Influencing factors of high energy consumption households and utilization of appliances

2.2.1 Linear regression of electricity consumption

The energy consumption in the survey comprises of electricity and gas consumption, which was calculated from household expenditure on electricity and gas. In this study, there are more influencing factors for electricity consumption. The influencing factors include demographic factors such as family income, family size, age of respondent, education, gender, state, remoteness (major city or remote) and building characteristics such as floor area, block area, window type, and insulation.

In this research, several methods were carried out to evaluate the relationship between electricity consumption and the influencing factors described above.

At the beginning, forward stepwise regression was conducted in the statistic software GenStat® to find the most significant explanatory variables for electricity consumption. However, the result did not show as expected. After trying all the factors step by step, the percentage of variance only account for about 24.7%. That means when the explained variable is electricity consumption and the explanatory variables are the influencing factors above, only 24.7% of all the data can fit the regression equation. On the other hand, in the first step of regression using only one single explanatory, the result shows the factor of family size can explain more variance than the other demographic factors. Following are cluster analysis and Chi-square test to show more visualized relationship between those influencing factors and the electricity consumption.

2.2.2 Cluster analysis and Chi-square test for appliances utilization

Cluster analysis is to used divide the respondents into several groups according to their characteristics. In this study, a two-step cluster was done in SPSS according to the respondents' utilization frequency of appliances: television, dishwasher, and clothes dryer. These three appliances are significant for predicting the residential energy consumption in China. In the 2009 Annual Report on China Building Energy Efficiency [13], it is pointed out that the energy consumption of clothes dryer and dishwasher in a typical US family is equal to the total energy consumption of a typical family in Beijing. And recently new apartments tend to take installation of these machines as a symbol of modern life.

By the two-step cluster in SPSS, four clusters are available. The utilization frequency of the three appliances is shown in figures 2.2.2-1 (a), (b) and (c). Taking figure2.2.2-1 (a) as an example, it shows the utilization frequency of clothes dryer in the four clusters. In cluster 4, there are 654 households (N=654), of which 40% households use the clothes dryer some days or more. Here "Some days or more" stands for the combination of the options "Some days", "Most days" and "Once a day". In cluster 3, there are 518 households and 100% of them answered they do not have a clothes dryer. Dark color means more use, while light color means less use.

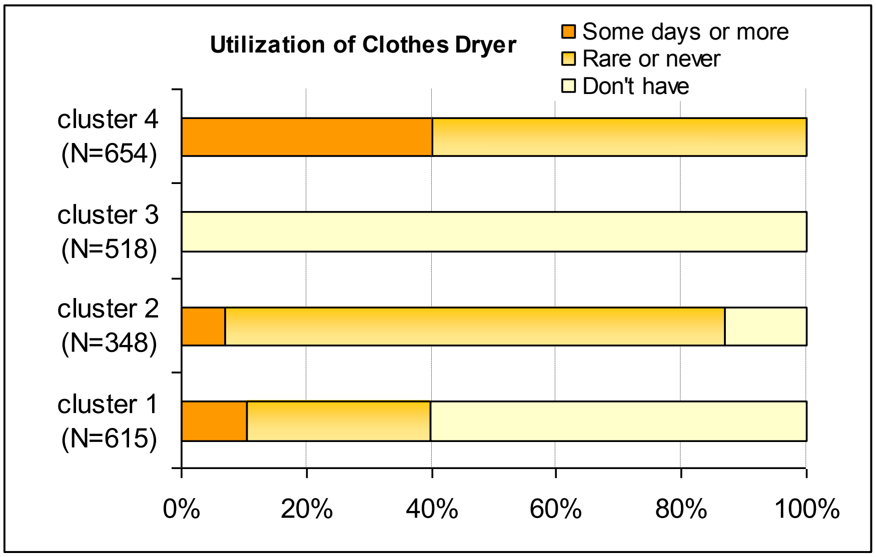


Figure2.2.2-1 (a) utilization frequency of clothes dryer in 4 clusters

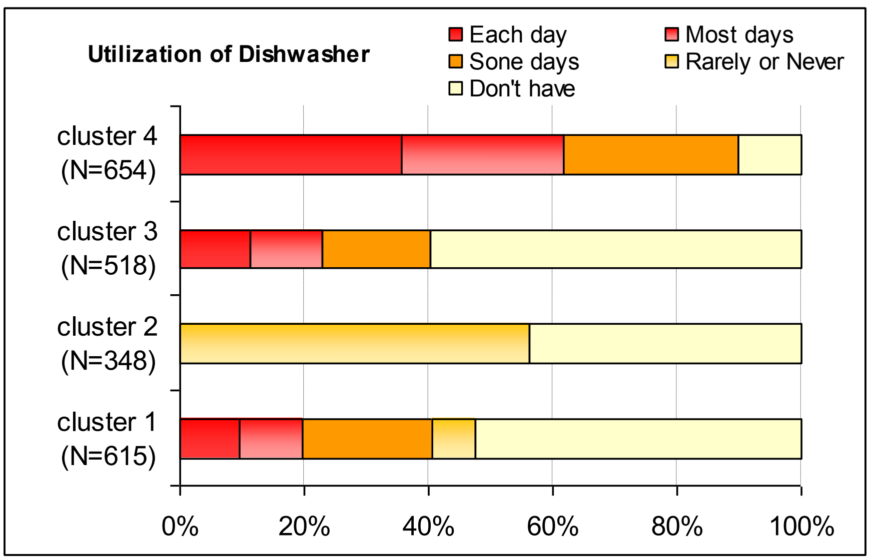


Figure2.2.2-1 (b) utilization frequency of dishwasher in 4 clusters

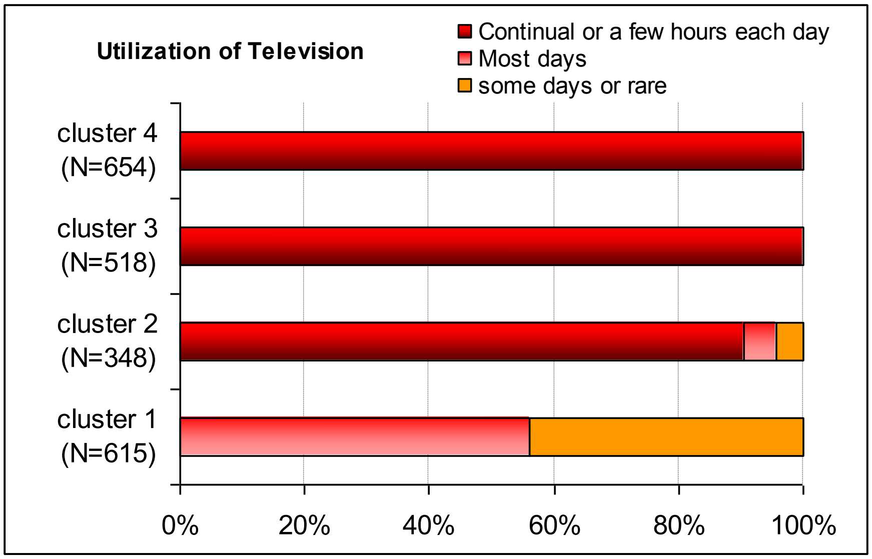


Figure2.2.2-1 (c) utilization frequency of television in 4 clusters

In summary, these three figures show that the highest use of all appliances appears in the same cluster (cluster 4). They also show that the lowest appliance use is spread across the other three clusters. Cluster 3 does not own clothes dryers, Cluster 2 has the lowest dishwasher use and Cluster 1 has the lowest television use.

Cluster 4 has the most frequent use of all three appliances. It is therefore important to look into how the energy consumption and influencing factors in cluster 4 differ from the others. As shown in figure 2.2.2-2, the average electricity bill in cluster 4 is 978 Australia dollars, which is much higher than the other clusters and can be taken as a high electricity consumption cluster.

The influencing factors to be evaluated here include the demographic factors of family size, family relationship (single, couple, single parent, couple with children), income, gender of respondent, age of respondent, education level, state, remoteness (major city, remote) and building factors of housing type (separate house, apartment) and floor area.

As discussed above in the linear regression, the factor family size appears to be most closely correlated with the electricity consumption. Figure 2.2.2-3 below shows that the average family size in cluster 4 is 3.12 persons, much higher than the other clusters. A big size family usually accompany with more working members which will result in more income. Therefore the factors big family size and high income would appear at the same time in a high energy consumption household.

Considering the influence of family size on other factors, Chi-square tests should go ahead first to examine whether the influencing factors are independent from the family size or not. Based on the Chi-square test at the 0.05 level, all the influencing factors were divided into two groups according to whether they are independent from the factor family size. And then the crosstabulation and Chi-square test were taken to evaluate whether the influencing factor make significant difference in different clusters and which cluster shows the difference.

As shown in table 2.2.2, the influencing factors in group 1 include the family relationship, income, age, housing type, floor area, all of which are dependent on the factor family size. On the contrary, the group 2 factors which are independent from the family size include gender, remoteness, state, and education level. Three conclusions can be drawn from the table:

a) The factors in group 1 are dependent on the family size and at the same time all of them make significant difference in cluster 4. In another way, all the factors in group 1 are the characteristic of cluster 4, which stands for the high electricity consumption family. Therefore, the high electricity consumption cluster tends to concentrate in big families, and correspondingly have higher income, bigger separate house, and the family relationship is couple-with-children therefore the average age is elder than the single or couple-without- child family.

b) The factors in group 2 are independent of the family size. And all of them do not make significant difference in the cluster 4.

c) In this case the high energy consumption family (cluster 4)'s average age (age of the respondent) is older than other clusters. However, it can not certainly come to the conclusion that older people are the driving force and influencing factor on high energy consumption. It may be because the person with children will be older than the single or couples without child. It is very important to think about whether a factor is dependent on another factor or not.

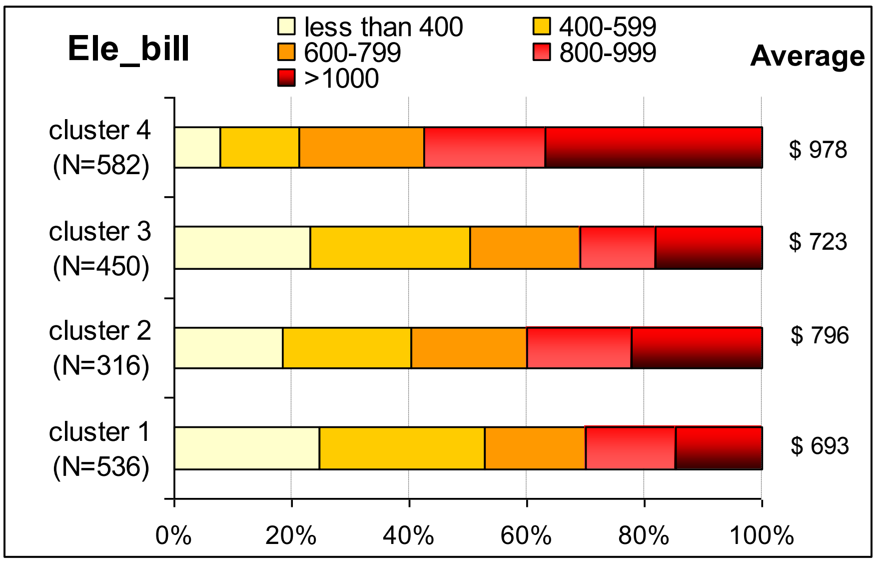


Figure 2.2.2-2 Electricity bill in 4 clusters

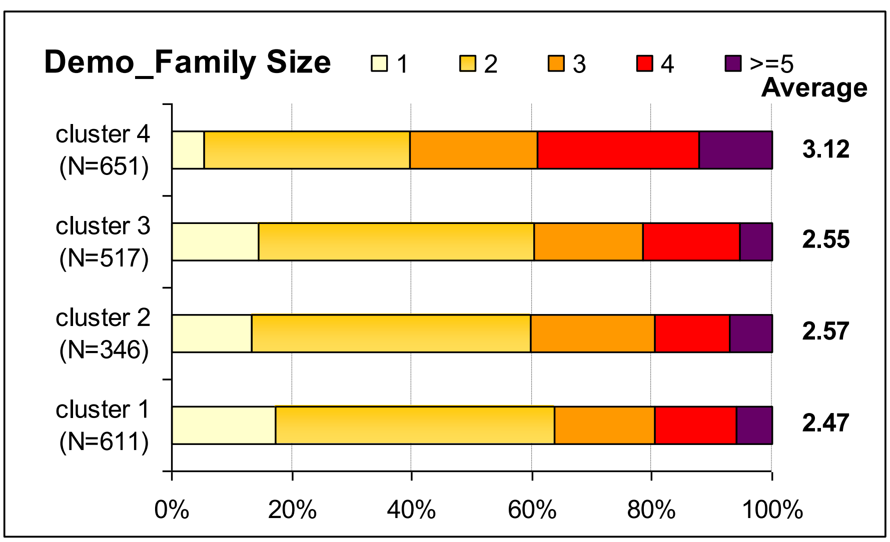


Figure 2.2.2-3 Family size in 4 clusters

	Influencing factors	Independent of family size	Chi-square test result (Significant different in 4 clusters)	Cluster showing difference	Characteristic Of the cluster
Group 1	**Family size**	NO	YES	Cluster 4	Bigger family size
	Family relationship	NO	YES	Cluster 4	Couple with children
	Income	NO	YES	Cluster 4	High income
	Age	NO	YES	Cluster 4	Older
	Housing type	NO	YES	Cluster 4	Separate house
	Floor area	NO	YES	Cluster 4	Bigger
\ Group 2	**Gender**	YES	NO	/	/
	Remoteness	YES	NO	/	/
	State	YES	YES	All clusters	/
	Education	YES	YES	Cluster 1	Lower education

Table 2.2.2 Influencing factors cluster 4

2.3 Income and residential energy consumption

From the discussion above, to a certain degree the factor income is dependent on the family size. This section is going to focus on the energy consumption per capital and the income per capita. In the questionnaire, the electricity bill per year and the whole family's income per year were investigated. The responses were categorical rather than continuous.

Table 2.3-1 shows the number of households in each income category. Cells with less than five households are excluded. For each cell, for example, in the case where the family size is four and the whole household income is 60000~99999 AUD per year, there are 101 respondents, and the average electricity consumption of these 101 households can be approximately calculated. Figure 2.3-2 shows the results for all the cells except the cells containing less than five respondents.

		What is your gross annual household income?					total
		0 - 19999	20000-39999	40000-59999	60000-99999	more than 100000	
How many people usually live in your household?	one	23	45	56	120	18	262
	two	17	61	109	265	446	898
	three	5	27	43	121	206	402
	four	12	11	40	101	218	382
	five	5	3	7	41	67	123
	six or more	2	1	6	14	18	41
Total sample		64	148	261	662	973	2108

Table 2.3-1 The number of households that fall into each income category by household size. Household income is in Australian dollars.

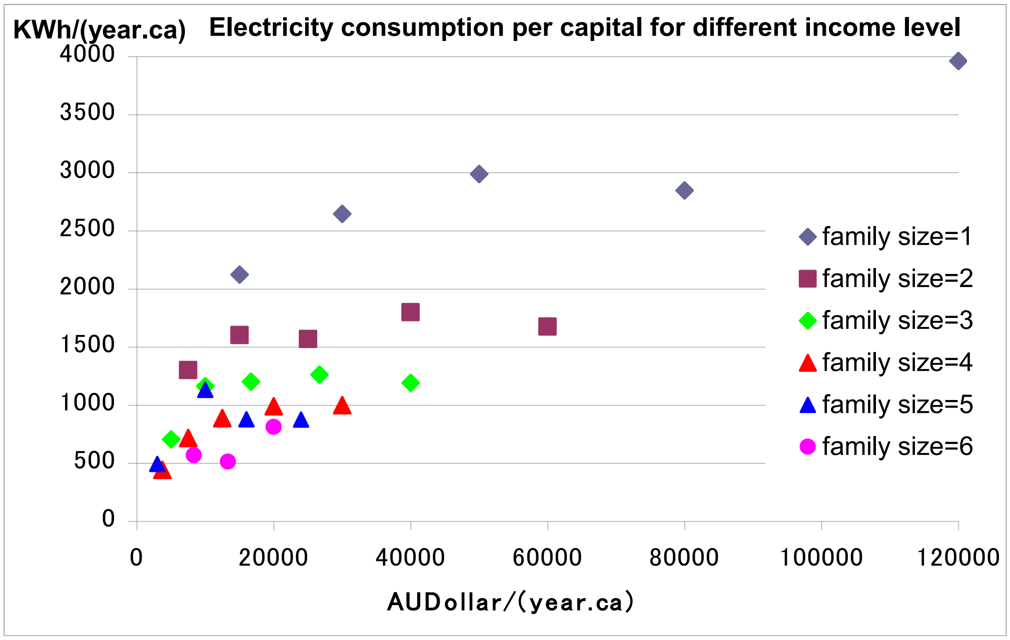


Figure 2.3-2 Relationship of electricity consumption and income

Three conclusions can be summarized from this figure:

a) The income and electricity consumption per capital decrease as the family size become bigger.
b) For certain family sizes, the electricity consumption per capita increases with income and then stabilizes. This trend is obvious especially when the family size is 2, 3 and 4, of which the sample numbers account for the largest proportion and then can stand for the common case in Australia.
c) In the case of single person with the highest income, the energy consumption is extraordinarily high.

3. Income and residential energy consumption in China

3.1 GDP and residential energy consumption

The residential energy consumption accompanied with the economic development in China is increasing very quickly. In the China Energy Statistical Year book, the final energy consumption involves several sectors such as agriculture, forestry, residential consumption and so on. Taking a focus on the time series from 1991 to 2004 for the residential consumption, figure 3.1-1 shows that in 2004 the residential energy consumption reached 212.81 million tons of standard coal equivalents (MTSCE), 33% increase compared with 1991[10]. However, considering the demographic factor of population, the residential energy consumption per capita increase is only 18.2%.

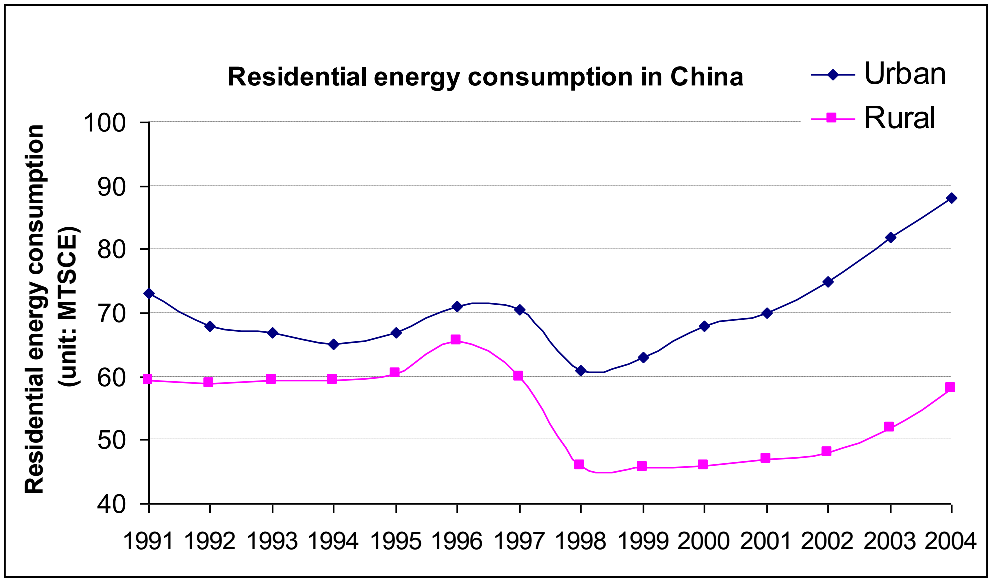


Figure 3.1-1 Residential energy consumption in China

3.2 Income and residential energy consumption in some cities

There is some research from a macroeconomic perspective using GDP and energy consumption data to analyze their relationship. However, publication of nationwide survey about the relationship of income and residential energy consumption is very limited even when the survey has been done. Actually in many cities, the local statistic bureau takes several hundred families as observed samples, recording their income, expenditure and other demographic factors. However, such data is not published and direct analysis using the indicators of income and electricity bill rarely shows in the literature.

Here we briefly consider the three cities of Shanghai, Wenzhou, and Zhanjiang, of which the GDP per capital is 10529 USD, 4413 USD, and 2203 USD respectively, representing three different levels of economic development. The data source is the local statistic bureau, but the method to obtain this data is by referring to news on the internet and email communication. In Shanghai, according to a sample survey in 2007, the electricity consumption of the top 20% high income households is 1.7 times of the 20% low income family. The proportion of electricity bill in the whole income is 2.3% in the high income household and 4.6% in the low income household [14]. The situation is similar in Wenzhou and the electricity bill in high income family is 2.26 times of that in low income family [15]. However, in Zhanjiang, after communication by email with the staff in statistic bureau, we found the energy consumption is higher in high income family but the proportion of energy expenditure in the whole income is lower in high income family.

This is the basic study about the situation, and more detailed analysis is needed for the reason behind such phenomenon.

4. Discussion

As China heads toward a moderately prosperous society, there is no doubt that the household income as well as living standard would improve national wide in the near future. Therefore it is very significant to consider about how the residential energy consumption would change with the economic development.

A comparison of the residential energy consumption between China and developed countries would be helpful to understand the current situation and projection for the future. Figure 4.1-1 is the comparison of residential energy consumption in China, Japan and Australia [5] [13] [16] [17]. For energy consumption per capital, the difference is great between the three countries. The energy increasing potential is huge as the lifestyle is changing forward a modernized and mechanized way.

	China Urban	Japan	Australia
Annual total energy (PJ)	4362	1582	420
Annual Energy consumption per capital (GJ/ca.a)	7.8	12.4	20.9
Annual energy consumption per area (GJ/ m^2.a)	0.39	0.45	0.36

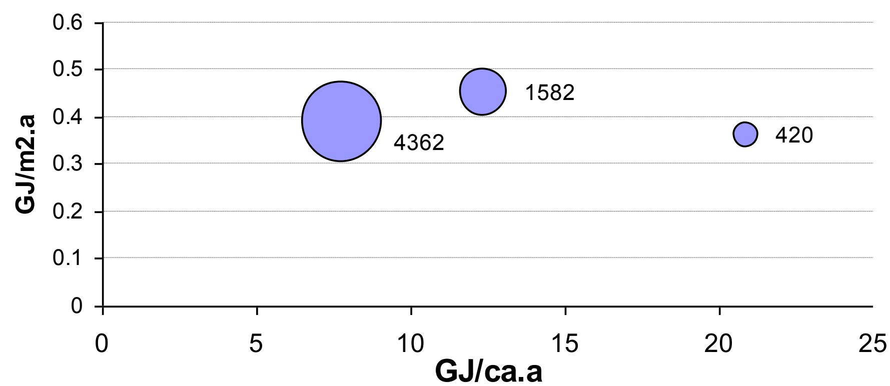


Figure 4.1-1 Comparison of REC between China, Japan, and Australia

From the income-energy consumption curve discussed above, it can be seen that only after the income per capital reach 20000 AUD, the energy consumption would not increase with the income. That means before a certain income level, the purchasing of some appliances as well as the some energy consuming lifestyle would be considered carefully and not accepted by the family.

According to a report from International Monetary Fund (IMF) in 2010, the purchasing power parity (PPP) per capital in Australia is 39,692 USD but 7518 USD in China. It is obviously that as the income level in China goes up, the purchasing of appliances such as refrigerators, air conditioners and even clothes dryers would become common in a household. In the big cities such as Shanghai, Beijing, and Shenzhen, the PPP per capital have already reached over 20,000 USD, however, the residential energy consumption in these cities are increasing very quickly now without any evidence of a turning point.

Though the energy consumption is increasing remarkably in many households in China, surprisingly this increase does not bring any attention or pressure for them to think about energy conservation. On the contrary, people take it for granted that economic development would certainly result in high energy consumption, and that high energy consumption in the family is a symbol of high standard of living.

Actually some kinds of living style are worthy of careful consideration. For example, why the balcony has to be replaced by the clothes dryer, why we discard the sunshine but use electricity instead. Something traditional does not necessary be changed to a so call modernized way.

5. Conclusion

For projecting the residential energy growth in China due to the great economic development, some experience and evidence can be found out from the current situation in developed countries. In this paper the analysis is based on a national survey in Australia. The authors focus on the influencing factors and aim to find out how income acts as a driving force for high energy consumption. However, these factors are to a certain degree dependent on each other. Therefore the analysis is carried out step-by-step to evaluate the significance of each factor.

In the second section, a regression is first carried out and shows the family size a more significant factor than income or other factors, though the electricity consumption does not explain much more variance when including all the available variables , such as family size, income, and floor area and utilization frequency of appliances.

Cluster analysis was then done based on the utilization frequency of television, dishwasher and clothes dryer. A Chi-square test shows the factors dependent on family size include family relationship, age, income, housing type, and floor area; while the factors independent on family size are gender, remoteness, education, and state. The most important thing is the factors dependent on family size all shows significant difference in the high energy consumption families (cluster 4), while the factors independent on family size all show no difference in high energy consumption. This result shows in Australia the family size may be the biggest influencing factor. At the same time it is necessary to consider the dependence between factors.

In the final part of the second section, the analysis aims to consider the income factor separately without interference of family size. The curve of energy consumption in different income level and different family size is made. For a certain family size, the electricity consumption per capital increase with the income and then stabilises at approximately $20000 annual per capita income.

In the third section, the residential energy consumption in China is analyzed. From the national level, the total residential energy consumption is creasing very quickly in recent years. The discussion then comes to three cities, representing three different level of economic development. It is the same in three cities that the energy consumption is high in high income family. However the percentage is different. In Zhanjiang, the percentage of energy bill in the whole income is big in high income family.

In the discussion part, the PPP in the whole of China and some cities are compared with Australia, the result infers of great increasing potential for the residential energy consumption in China. For a sustainable development way, some traditional living way should be kept rather than replaced by modern mechanical lifestyle.

References

[1] National bureau of statistics of China, *China Statistical Yearbook 2004,* China Statistics Press, Beijing, 2004.

[2] Reinders AHME, Vringer K, Blok K. *The direct and indirect energy requirement of households in the European Union.* Energy Policy 2003;31(2): 139e53.

[3] International Energy Agency, *World Energy Outlook 2004,* OECD, 2004.

[4] Michael A. McNeil, Virginie E. Letschert. *Modeling diffusion of electrical appliances in the residential sector.* Energy and Buildings 42 (2010) 783–790

[5] ENERGY USE IN THE AUSTRALIAN RESIDENTIAL SECTOR 1986 – 2020. *Department of the Environment, Water, Heritage and the Arts,* Commonwealth of Australia, 2008.

[6] Lenzen M, Wier M, Cohen C, Hayami H, Pachauri S, Schaeffer R. *A comparative multivariate analysis of household requirements in Australia, Brazil, Denmark, India and Japan.* Energy 2006;31(2e3):181e207.

[7] Jorge Alberto Rosas-Flores, David Morillon Galvez. *What goes up: Recent trends in Mexican residential energy use.* Energy 35 (2010) 2596–2602.

[8] Shonali Pachauri, Leiwen Jiang. *The household energy transition in India and China.* Energy Policy 36 (2008) 4022– 4035

[9] Joseph C. Lam. *CLIMATIC AND ECONOMIC INFLUENCES ON RESIDENTIAL ELECTRICITY CONSUMPTION.* Energy Converse. Mgmt Vol. 39, No. 7, pp. 623-629, 1998.

[10] Zha Donglan , ZhouDequn, ZhouPeng. *Driving forces of residential CO^2 emissions in urban and rural China: An index decomposition analysis.* Energy Policy 38 (2010) 3377–3383.

[11] SQ Chen, NP Li, Jun Guan, YQ Xie, FM Sun, Ji Ni. *A statistical method to investigate national energy consumption in the residential building sector of China.* Energy and Buildings 40 (2008) 654–665.

[12] Graham, S., Schandl, H., Williams, L. (2009) *A Snapshot of the Lifestyles and Consumption Patterns of a sample of Australian Households.* CSIRO Sustainable Ecosystems, Canberra

[13] *2008 Annual Report on China Building Energy Efficiency (white book)*, China Architecture & Building PRESS, Beijing, 2008

[14] Province Data Net. http://provincedata.mofcom.gov.cn/communique/disp.asp?pid=44205

[15] *Online News of Zhejiang.* http://zjnews.zjol.com.cn/05zjnews/system/2009/07/14/015670045.shtml

[16] Environmental impact of household energy use, Australia Bureau of Statistics.

[17] INOUE TAKASHI, MIZUTANI SUGURU, TANAKA TOSHIHIKO. *ENERGY CONSUMPTION IN HOUSING ON THE BASIS OF NATIONAL SCALE QUESTIONNAIRE Analysis of influence of various factors on annual energy consumption Part 2.* Journal of Environmental Engineering (2006) 75- 80.

Whole of House End Use Metering in Australia: gathering data for more informed policy

Lloyd Harrington, Jack Brown, Rob Harrington

Energy Efficient Strategies, Australia

Abstract

Many of the appliance energy consumption estimates available in Australia rely on research undertaken in a limited number of states. There has never been a comprehensive Australia-wide residential sector end-use study for electricity or gas consumption. Recent studies have highlighted the paucity of reliable end-use data for residential energy use in Australia [5].

The development of sound energy policy relies on an understanding of energy consumption. Without knowledge of how and why energy is used, the development of energy saving programs can only be based on educated guesswork. Given the strong political imperative to reduce greenhouse gas emissions in response to climate change, there is an increasing need to improve our understanding of energy consumption in all sectors. Modern, relatively inexpensive monitoring equipment with remote download options is now available, making this task more achievable.

The current Australian Residential Energy Metering Program (REMP), has a two purposes:

- To develop a better understanding of the energy and water consumption of all end uses found in a home; and
- To develop a comprehensive hardware and methodology structure for end use metering projects, allowing wider stakeholder uptake and greater opportunities for collaboration.

The initial phase of the REMP started with a five house pilot project in early 2010, within which data collection and validation techniques, demographic survey approaches, and metering technologies were trialed and tested. About 60 end uses are being monitored every minute in each house. The pilot phase has thrown up an incredibly rich data set for the analysis of user interactions with appliances and the potential impact of appliance efficiency on total energy use. The data also allows the impact of weather and occupancy on energy consumption to be analysed and gives excellent information on drivers of peak electricity demand.

The results of this pilot phase are being used to design a larger, longer running end use study. The paper will outline lessons from the pilot and potential directions for a larger national study.

Background

The development of sound energy policy relies on an understanding of energy consumption. Without knowledge of how and why energy is used, the development of energy saving programs can only be based on educated guesswork. Given the strong political imperative to reduce greenhouse gas emissions in response to climate change, there is an increasing need to improve our understanding of energy consumption in all sectors in order to develop and introduce effective energy saving policies. Key applications of end use data may include:

- Developing programs to reduce energy consumption;
- Assessing the impact of improved equipment efficiency;
- Examining the impact of fuel switching;
- Projecting future energy consumption and greenhouse emissions;
- Quantifying the energy consumption at the household level, including understanding the impact of user behaviour;

- Assessing energy savings from load management and controls;
- Evaluating the success of a range of energy-related programs; and
- Quantifying the drivers of peak load and assessing the effectiveness of demand response measures.

In most cases, this will be best done by:

- Understanding the relationship between laboratory energy consumption (standard test conditions) versus actual use in situ conditions;
- Validation of (and improvement to) end-use models which are generally the basis for energy projections, product policy appraisals and evaluations.

There have been few end use metering campaigns in Australia over the past 20 years and they have been done on a small scale and on an ad hoc basis, so there is little firm data on energy consumption of appliances in the field. In contrast, government has already or is proposing to regulate the energy efficiency household appliance sales worth some $6 billion a year in 2008, in addition to the cumulative energy bills for these products, which is substantially larger. So an improved understanding of energy end use is clearly warranted.

Factors that drive energy consumption during normal use

The energy consumption of equipment during normal use is affected by a number of different factors:

- Number of energy consuming devices present (also called ownership or stock of appliances and equipment).
- Attributes of the products in terms of the output or energy service provided, energy consumed, various states and modes, technical efficiency etc.
- User interactions with the products - frequency and duration of use, which to some extent is driven by factors such as demographics and occupancy.
- Climate or weather factors for some product types (mostly space heating and cooling, and to some extent refrigeration).

It is important to understand the impact of each of these factors with respect to end use energy consumption and which elements can be best determined from end use metering and which elements require the use of other data sources.

Ownership - the number and type of appliance and equipment in service within the stock needs to be established through large scale surveys of the population. Due to the relatively small sample sizes, end use metering campaigns cannot provide accurate ownership data on the stock of appliances in the field. So it is critical that any appliances measured within an end use metering campaign be mapped back to the national stock of appliances wherever possible and scaled up as appropriate.

Attributes – appliance attributes cover a range of important aspects of energy consumption including the size, energy service provided, the energy consumption (for a specified task) and the technical energy efficiency. Conceptually, these attributes can be thought of as the physical and energy related characteristics of an appliance. Ideally, the best place to establish most of these attributes is in a test laboratory where an accurate assessment of the all of key parameters can be undertaken with accuracy under controlled conditions. This is why field measurement of appliance models that have been tested in a laboratory are always preferable to unknown models. It is practically impossible to measure the operating efficiency of many appliances through end use metering.

User interactions - this is perhaps the key parameter that can only be established from direct end use measurements with any accuracy. In many cases, user interactions are the key driver for energy consumption (hours of watching a television, loads of washing per week). The key problem with user interactions is that by nature these are highly diverse from user to user (and even from day to day within the one house) and therefore special approaches need to be applied to characterise these highly variable distributions. There will be some uncertainty on the mean usage and the distribution of the usage patterns across the population. Therefore examining the drivers for diverse consumption at a user level is also important – these may be random or related to demographic or other user related factors.

Weather and climate – these effects are perhaps the most complex of all end use related measurements. The drivers for space heating and cooling energy consumption are a combination of weather, building shell thermal performance (including materials, insulation, glazing, orientation and shading), occupancy and zoning within a house (the latter 2 being user related effects). Energy measurements of heating and cooling energy consumption in isolation is of little strategic value unless there is also an assessment of the impact of the other 4 key elements – weather, building shell, occupancy and zoning. An example of an appliance that is also partly affected by weather and climate is household refrigerators and freezers. Ambient temperature has a substantial impact on the underlying energy for these products, so at a minimum indoor temperatures need to be measured as part of a monitoring program. Lighting is also partly affected by weather and seasons, and some other end uses may also show seasonal effects (eg dryers, hot water and even televisions).

The metered energy consumption of an individual appliance is a function of the appliance technical characteristics (most importantly the energy efficiency) and the user interaction with the appliance (and to some extent the ambient conditions for some appliances). The objective of end use measurement campaigns should be to disaggregate the key factors that affect the energy consumption in a way that allows the influence of the technical characteristics of the appliance (its efficiency) and the user related elements to be characterised and separately quantified in a generic fashion. This then permits separate analysis of the stock of appliances and the user related aspects. When analysed in this way, the energy impact of substituting more or less efficient appliances can be readily estimated if they were to be replaced in the stock. This is the key information that policy makers really want to know – how much energy can be saved by the use of more efficient appliances during normal use. This can only be done accurately in the context of actual usage parameters.

Due to the complexity and expense of end use metering equipment, the monitoring of end uses generally has to be restricted to a relatively small sample of products (small number of houses measured, limited number of end uses per home measured directly). So it is important that the end uses selected, as well as the particular products selected, are well documented and understood. However, if there is good information on the characteristics of the total stock of appliances of a particular type, it can be possible to scale up the results from even a small sample of metered appliances to get a good estimate of total stock energy. The most important element is the scaling up of the user related parameters which can then be applied to the known stock characteristics, rather than the actual energy consumption that has been measured.

End use metering objectives

The key drivers for undertaking an end use monitoring program are many and varied and depend on the requirements of the client or proponent. Their motivation and rationale will dictate the key appliances of interest. Focus on just a single appliance, while justified many some cases, means that there may be fixed costs (such as site visits) that make the data collected relatively expensive per appliance. However, targeting a single or small group of appliances means that much larger samples can be obtained when compared to comprehensive whole house monitoring. In general terms, as much data as possible should be targeted within the available budget within a particular end use metering campaign.

There is also a strong government interest in appliances that are already regulated for energy efficiency in order to keep these programs relevant to users (ongoing program maintenance, improved evaluation through better understanding of in situ use, upgrading programs to more closely align with typical consumer use). Products that are proposed for regulation of other energy programs are also an obvious target for end use metering. There is also interest in building shell performance issues as this is regulated in many places.

In general, policy priorities for government will naturally concentrate on end uses with large energy consumption, end uses with a large energy savings or greenhouse gas reduction potential, those with high or increasing ownership as well as those products where policies are already in place. In particular, end uses where little data is available and where end use metering offers the only practical information source will also be a focus. To some extent, key and emerging products can be identified from an intelligent combination of detailed ownership surveys and ongoing measurement of products in laboratories and limited measurements in the field.

While monitoring of individual product types and end uses is attractive from a total cost perspective, whole house integrated monitoring is essential for some types of end use analysis. In particular:

- Lighting – due to the large number of individual end uses typically found in a home.
- Space heating and cooling – due to complex interactions with users, weather and building shell performance and the use of multiple or central appliances in many cases.
- Peak load drivers – understanding the main causes of peak electricity loads is becoming a critical factor in many countries. Given that there are literally up to 100 appliances and in some cases up to a couple of hundred individual lamps in a large house, isolating the key drivers of peak load requires a comprehensive approach to monitoring.

Pilot homes

The government in Australia is developing a comprehensive strategy for end use metering in Australia. This has involved:

- Review of end use metering hardware options
- Commissioning comprehensive end use metering in 5 pilot homes in Melbourne
- Preparation of detailed background papers on recommended approaches to end use metering for more complex end uses
- Development of a comprehensive data strategy and database structure.

Initial documentation on these phases is available in REMP (2010) [1].

End use metering equipment was installed in the 5 pilot homes in February 2010 and is continuing to operate. The main objective of the pilot phase was to:

- Undertake field assessments of the equipment selected
- Refine procedures for household recruitment, liaison, information and documentation
- Fully assess requirements for equipment installation and commissioning, including the use of personnel and tradesmen (plumbers and electricians), where necessary
- Assess the selected end use metering equipment in a practical environment
- Develop and refine data downloading, verification, processing, cleaning and analysis procedures
- Develop software and systems for analyzing data and producing selected outputs.

To fully assess all of these systems, equipment to provide comprehensive coverage of end uses in each of the 5 pilot homes was installed. The end use equipment for each home consists of:

- Separate monitoring at the switchboard for every circuit (on average 12 circuits per home – some of these are dedicated to particular appliances)
- In line metering of 24 major plug in appliances and plug in lights in each home
- Light sensors for 12 hard wired lights in each home
- Hot water flow, inlet and outlet water temperatures, gas consumption

- Ambient sensors for temperature and humidity (inside and outside)
- Occupancy sensors in living areas.

Data from the in line meters, light sensors, hot water and ambient sensors are all collected via an internal zigbee wireless network. All parameters (wireless and switchboard data) are collected at 1 min intervals and this is automatically uploaded to an FTP server each hour via a GPRS modem. As the uploaded data files are compressed, automated systems have been developed to download and decode the data files and load this into an SQL database daily. Basic integrity checks identify missing data and any problems with equipment or sensors. This approach is excellent as it does not require any routine visits to the house to collect data or check sensors. Any equipment failure can be detected remotely. The current configuration has some data loss on the internal wireless system, but some system development is being undertaken to ameliorate this problem.

On installation, very careful documentation was prepared for each house. This is critical if any sense is to be made of the data collected. Information recorded included:

- Brand model and serial number of every appliance in the home (not just those metered)
- Spot power readings for all relevant modes of every appliance
- Full lighting audit recording for each lamp technology type, power, luminaire details, lights per switch, usage (heavy or light) and room dimensions and type.
- Full mapping of each power outlet back to an individual switchboard circuit
- Full mapping of each hard wired lighting point back to an individual switchboard circuit
- Recording which power outlet a plug in appliance or lamp is normally connected.

Mapping of circuits is time consuming but has been very important. By examining each circuit individually, it is possible to get detail on some unmetered appliances by looking at total circuit power and subtracting the appliances or lamps that are known to be on that circuit and which are directly recorded (so called residual power). Residuals also provide important checks on the power outlets to which appliances are connected – a negative residual suggests that a separately metered appliance has been moved to a different circuit (which happens from time to time).

The next phase of the project will be to prepare for a more comprehensive end use metering program for a larger sample over the coming years. But it is important to document what has been learned from the pilot so far.

Household audit

Separate to the end use metering being undertaken, an audit of household appliances and lighting is being undertaken in 2010/2011. This appliance audit builds on previous surveys of appliances conducted in 2005 [2] and 2000 [3] to assess standby power trends in homes. For appliances, every plug in appliance was documented and the power levels in each of the main modes was measured using special power meters. Information on the age, size and mode when found were recorded. The 2000 survey covered some 64 homes while the 2005 survey covered some 120 homes and nearly 8,000 appliances. The 2010/2011 survey will be completed in early 2011 and covers 150 homes and 11,000 appliances. These survey provide vital information on the ownership of many small appliances and equipment types not covered by large scale ownership surveys. They also provide a direct quantification of the power consumption in each mode which is essential for assessing standby power trends.

The 2010/2011 audit also provides comprehensive documentation on the stock of lighting in Australian household for the first time. This data provides invaluable insights to policy makers on the number and type of lights present, number of rooms and their size, lumen output, average Lux and a range of other parameters that are essential to assess overall lighting efficacy of the lighting stock. This type of audit is critical to put end use metering data in REMP homes into a larger context within the total lighting stock and should form a key component of any broad scale end use metering program.

Table 1: Key average lighting attributes in Australian homes - 2010

Attribute	Incand-escent	QH	CFL	Linear fluoro	LED	Unknown	TOTAL
Number/home	12.68	14.20	12.82	4.63	0.42	1.46	47.0
Number share	27.4%	30.7%	27.7%	10.0%	0.9%	3.2%	100%
Watts/lamp	95.7	54.2	14.1	31.1	6.7	46.3	50.8
Watts/home	1213	770	181	144	2.8	68 *	2388
Lumens home	14875	11916	9799	13168	131	891	48889
Lumens share	29.3%	23.5%	19.3%	25.9%	0.3%	1.8%	100%

Source and notes: Analysis of Australian lighting audit 2010/2011 for 71 homes – full sample to be included in final paper. Lighting energy consumption will be affected by usage patterns by lamp. Total number of lamps per home ranges from a low of 15 to a high of 220. * unknown lamps are assumed to be a 68W incandescent for the purposes of comparative analysis.

Approaches and lessons learned by major end use

Not only has the pilot project delivered an amazing array of end use data, it has provided some valuable insights into how to tackle some of the more difficult end use, which are of a general interest. Some of these insights and lessons are documented below.

Lighting

Lighting presents special problems as there are a large number of lighting points per home, each with a (possibly) different technology and power profile. While it may be technically possible to separately record data for each lighting point (typically using an event recorder linked to a light sensor), this is not generally practical for a large scale metering campaign. An average house in Australia has about 50 separate lights and some houses have over 200 lights. Lighting circuits are generally hard wired, which obviates the use of standard in line power meters for individual lighting points or circuits. Measurement of lighting circuits at the switchboard (if these are not mixed with power circuits, which is usually the case in Australia) can give total lighting energy but little information on which lighting points are used and which technologies are used to provide useful light. Other problems are the use of dimmers and the regular replacement of lamps during any monitoring period. Task or local lighting powered through normal power outlets can be readily measured with in line power equipment (typically about 5 to 10 per average home in Australia). A mixture of individual power circuit metering and light sensors on 10 or more lighting points in higher use areas appears to provide optimum information and energy breakdown by technology.

Work is under way to generate generic user profiles based on a questionnaire of usage by lamp which is then calibrated by end use metering data to refine actual usage patterns. The ultimate objective would be to get a user profile developed in terms of average Lux with some demographic drivers. This would allow an assessment of energy consumption impacts for substitution of all possible lighting types.

Hot water

Hot water is complex as there are many possible fuels sources (electricity (with controlled tariffs), gas, LPG, solar, heat pump, wood etc) and a range of hot water end uses. Hot water usage patterns are extremely variable at a household level and the main drivers for this variation are not well understood. There are also a range of energy losses associate with hot water production and storage (storage heat loss, combustion conversion efficiency) which cannot be assessed in the field and distribution losses in plumbing, which also cannot be assessed.

Measurement of water and gas consumption requires use of special meters and installation of equipment by plumbers. Energy input data for gas storage systems is difficult to interpret due to changes in gas properties and a range of complex interactions in the tank and the burner system.

Energy input measurements for complex systems like solar water heaters and heat pumps (which are now common) make any assessment of operating efficiency during normal close to impossible as a large range of instrumentation is required to assess the ambient input energy in these cases. Therefore, the assessment of operating efficiency in use cannot be practically assessed in many cases. External energy inputs are best estimated through modeling for a given hot water usage profile.

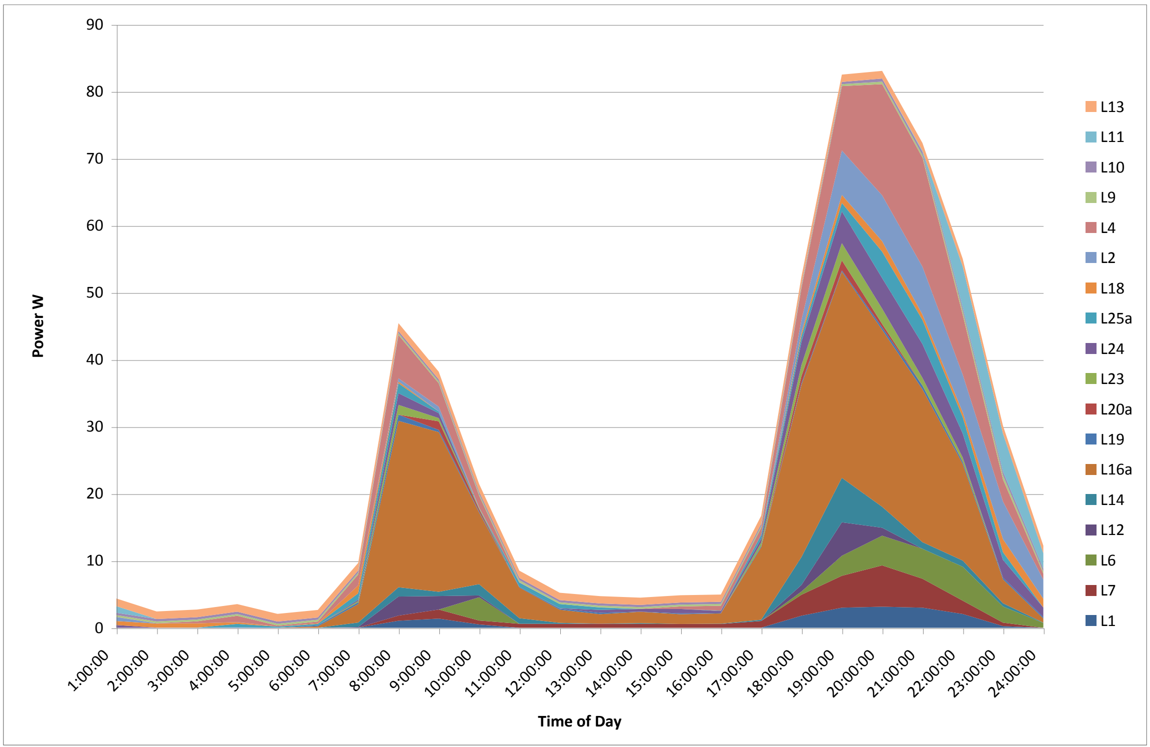


Figure 1: Average monthly time of day power consumption for lighting by lamp, May 2010

Hot water volume delivered is undoubtedly the most important parameter that drives total hot water consumption. Monitoring of hot water volume and temperature are ideal (which can be integrated to give energy output), although these are not simple to implement with accuracy. Measurement of hot water draw-off volume at 1 min level, which was used in the pilot homes, revealed that there are a large number of very small events in all homes (which of course leads to much wasted hot water). Many of these are less than a litre and the drivers are not yet understood, but are likely to be generate by tap use with so called flick mixers (their central position when off generates a mix of hot and cold water when lifted). Four of the houses had 25 to 30 hot water events per day while the single person house had about 12 events per day. Most of these were 2 litres or less in size.

The other key findings in the pilot homes was that total hot water demand was highly variable from day to day as well as from house to house. This is illustrated in Figure 1 and Table 1. One area where research is required is to look at ways of characterizing the distribution of draw-off events and total hot water per day (weighted distribution of events as share of total hot water consumption).

Table 2: Daily hot water usage from pilot homes in Melbourne March to November 2010

House	Average litres hot water per day	Standard deviation of daily use (L)
1	144	74 (51%)
2	64	29 (45%)
3	107	62 (58%)
4	56	46 (82%)

5	68	30 (44%)

Source: REMP end use monitoring. House 4 single person dwelling.

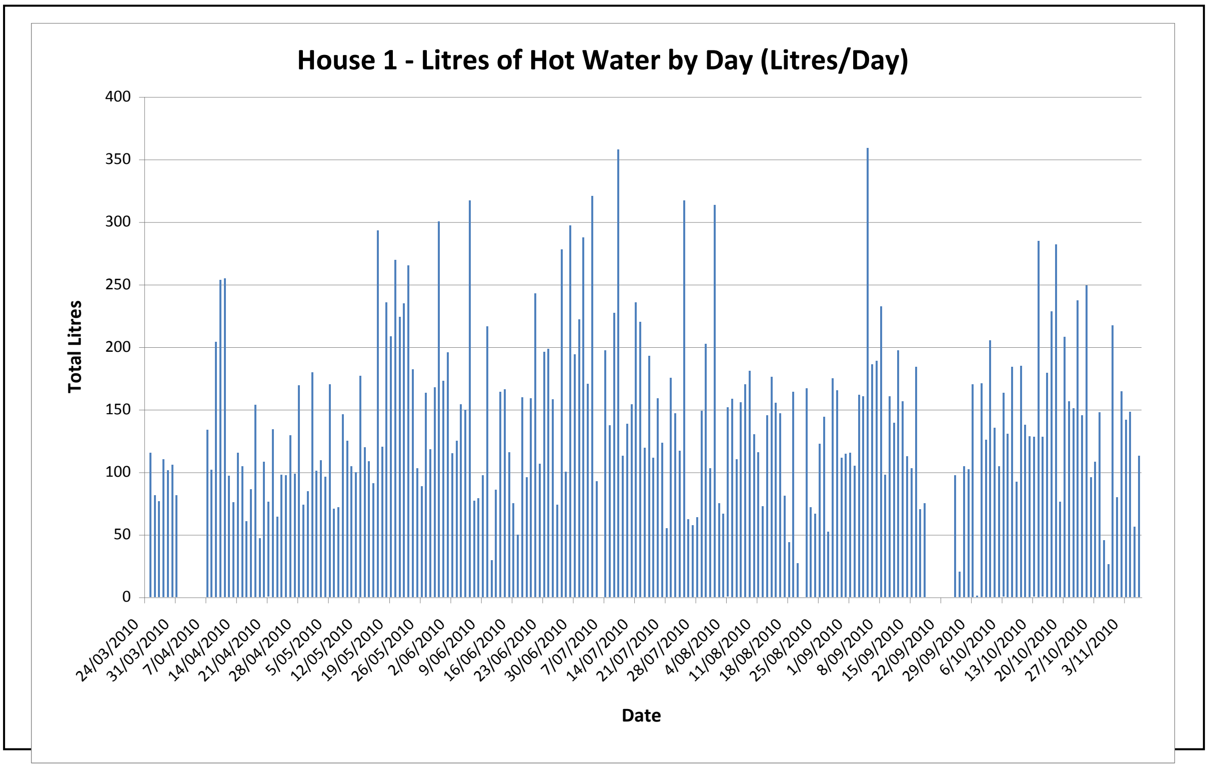


Figure 2: Daily hot water draw-off March to November 2010

Space heating and cooling

These are perhaps the most complex end uses to monitor. The primary heating and cooling requirement is dependent on building shell performance, the climate and changes in weather from day to day, which itself can be highly variable. There are also many possible fuel sources and associated appliances in different parts of the house (which can be operating in parallel) as well as combinations of technical efficiency and losses, most of which cannot be ascertained through energy metering in the field.

Occupancy and zoning, which is also a critical determinant for energy consumption, varies considerably by house and user and possibly from day to day. Temperature sensors around the home and outside are critical, although characterizing the effects of space conditioning from this data is not possible. Because the heating or cooling output cannot be measured directly from end use monitoring, it is critical to have good technical data about the performance of each piece of space conditioning equipment. This is the only way to estimate the likely output from space conditioning equipment.

A number of very useful parameters that can be determined from end use monitoring equipment with respect to space conditioning equipment. Some of these are:

- Occupancy patterns and their distributions.
- Linkages between occupancy and the use of space conditioning equipment (the mild climate in Australia tends to mean that space conditioning equipment is usually only operated when the occupants are at home).
- The extent of zoning when space conditioning equipment is used.

- Typical indoor conditions that trigger the use of space conditioning equipment (effectively set points for switching equipment on).
- Typical indoor temperatures selected by users when space conditioning equipment is operated.

It has been found that occupancy sensors, especially in living areas, provide useful data to indicate when occupants are around. As the effects of space conditioning are very complex, the actual energy consumption used by equipment is of little direct use. However, characterization of the key parameters above through end use metering will enable sophisticated building shell models to be more closely operated to reflect actual energy consumption during normal use. This is not important for comparative purposes (such as rating tools for building shells) but it is critical if these types of models are to be calibrated to reflect actual energy consumption and potential savings from building shell improvements and increases in space conditioning equipment efficiency.

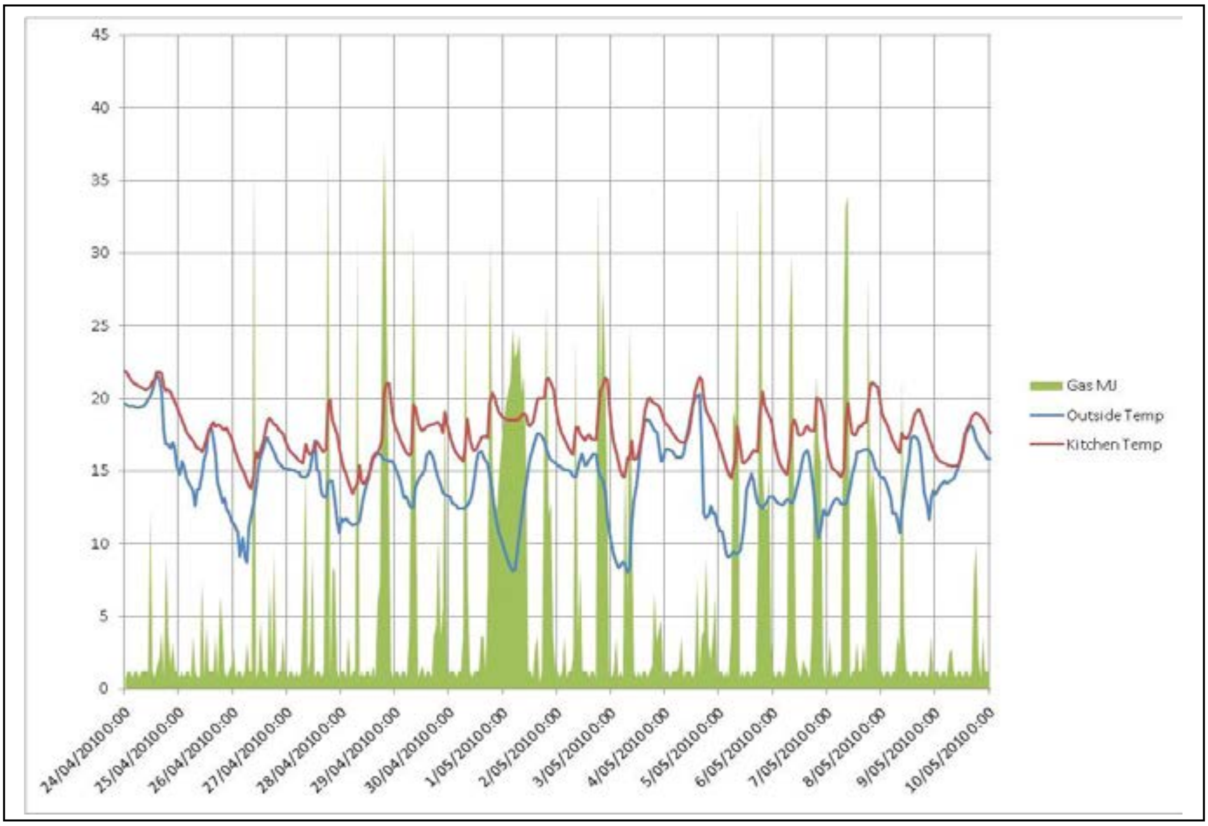


Figure 3: Space heating for a 5 day period in May 2010

Household refrigeration

Household refrigeration is an appliance that attracts a lot of attention because it is a significant end use in the residential sector (of the order of 20% of electricity consumption). Energy consumption is significantly affected by consumer usage (processing load (cooling down food and drink) and door openings (cooling air and removal of humidity)). Defrosting design and frequency of operation can also affect energy. As it is one of the few end uses that is always "on", the impact of user related actions and ambient conditions is less obvious when examining end use data.

There are practical limitations to what can be monitored on refrigerators in the field. Generally measurement of internal temperatures and door openings is not practical in normal homes using standard equipment.

To make any sense of end use data collected for refrigerators during normal use, it is necessary to separate the technical energy attributes of the refrigerator from the effects of actual temperature of operation and processing load generated by consumer use. The underlying energy consumption for household refrigeration in most cases is highly sensitive to indoor ambient temperature, so recording of nearby ambient temperature is critical. To correct for operating conditions during end use metering, it is necessary to have information on the temperature-power response curve of the individual appliance being monitored. Some estimate of processing efficiency is also necessary in order to estimate the heat load equivalent from usage back to a user related value (and not just the energy effect of that usage on the particular refrigerator being monitored).

Ideally each unit measured in the field should have available key data determined in a test laboratory. Unfortunately this type of data is rarely available. Over the past few years, EES has developed techniques to disaggregate data in this fashion form end use data. If end use metering data is available over a long period and a wide range of ambient conditions and user conditions, it is possible to develop a temperature-power response curve for the appliance. When defrost and recovery events (where applicable) and operating temperature effects are taken away from the actual end use data measured, the residual energy can be attributed to user related aspects. To perform this type of analysis, power data needs to be recorded every minute and ambient temperature data also recorded. The of power data alone for this type of analysis is only feasible for single speed compressors (inverters are too complex to permit analysis on their power profile alone).

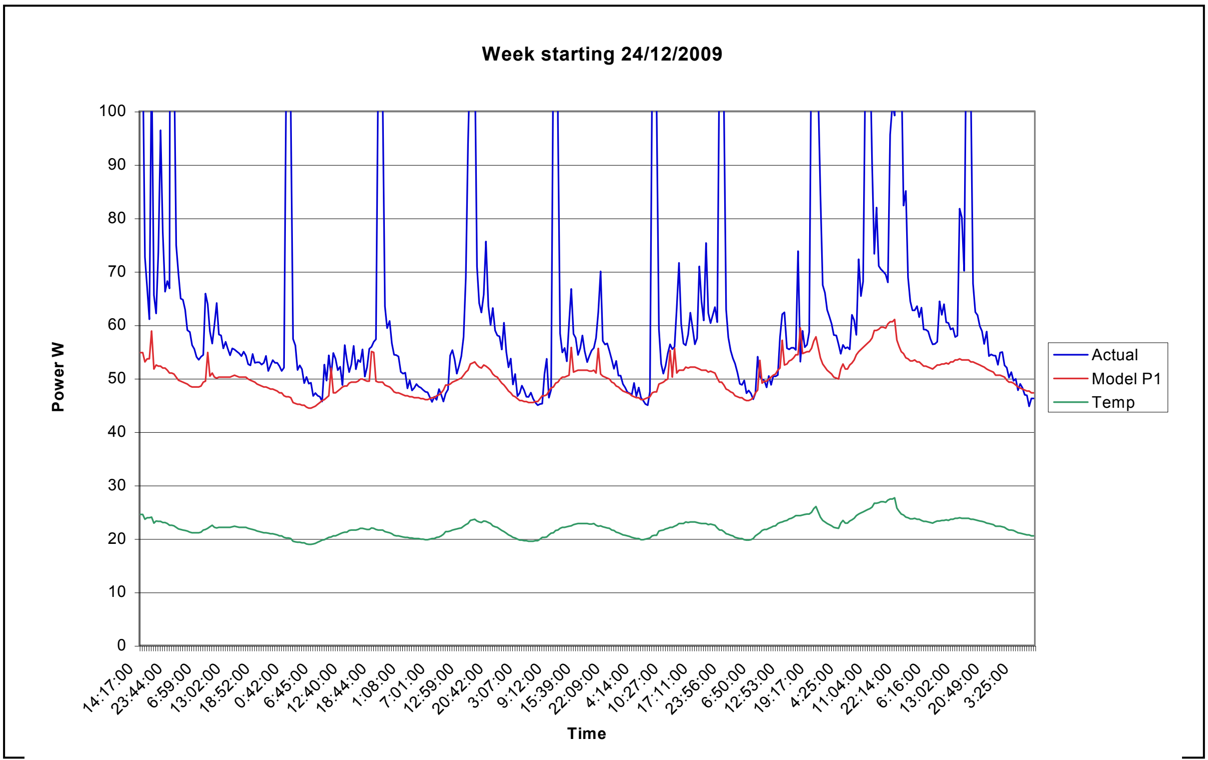


Figure 4: Analysis of end use refrigerator data

The blue line in Figure 4 illustrates the actual power consumption of a monitored refrigerator in a home (this has been normalized back to individual compressor cycles). The green line is the ambient temperature in the room and the red line is the estimated energy consumption of the refrigerator in the ambient temperature condition. The large spikes in the blue line are defrost events (about daily) and the difference between the blue and red lines is the affect on consumer use on the product.

It has been observed that seasonal affects in energy consumption are driven by changes in indoor ambient temperature as well as increases in user related loads in summer (as expected). These ambient temperature effects are less in some climates (eg northern Europe and North America) where space conditioning for large parts of the year tends to provide stable ambient operating temperatures for refrigerating appliances. Continuous space conditioning in Australia is fairly uncommon (due to the mild climate) do natural indoor temperatures tend to be more variable.

In the long term it is envisaged that laboratory test methods will routinely measure the ambient temperature-power response data for a refrigerator together with processing efficiency. Once the operating temperature distribution during normal use and the nature of processing load during normal use is quantified, this data can then be used to assess the relative energy during normal use of any refrigerator.

Wet Products

Some of these types of end uses are more complex in that the plug load does not easily convey the service provided to the user. For clothes washers, clothes dryers, dishwashers, there are a large number of possible programs and load sizes, all of which can affect the electricity consumption and which cannot be directly assessed through metering. In the case of dishwashers and clothes washers, the possible use of external hot water means that the product will be using energy from a separate source. This can be tracked if hot water is separately monitored in parallel. Clearly, documentation on the water connection mode for the appliance is critical as part of the product fiche. End use monitoring can provide frequency of use for these types of appliances where user interaction is associated with batches or cycles (eg clothes washers, clothes dryers, dishwashers). For these products, diary data may be a more effective way of gathering indicative program related data.

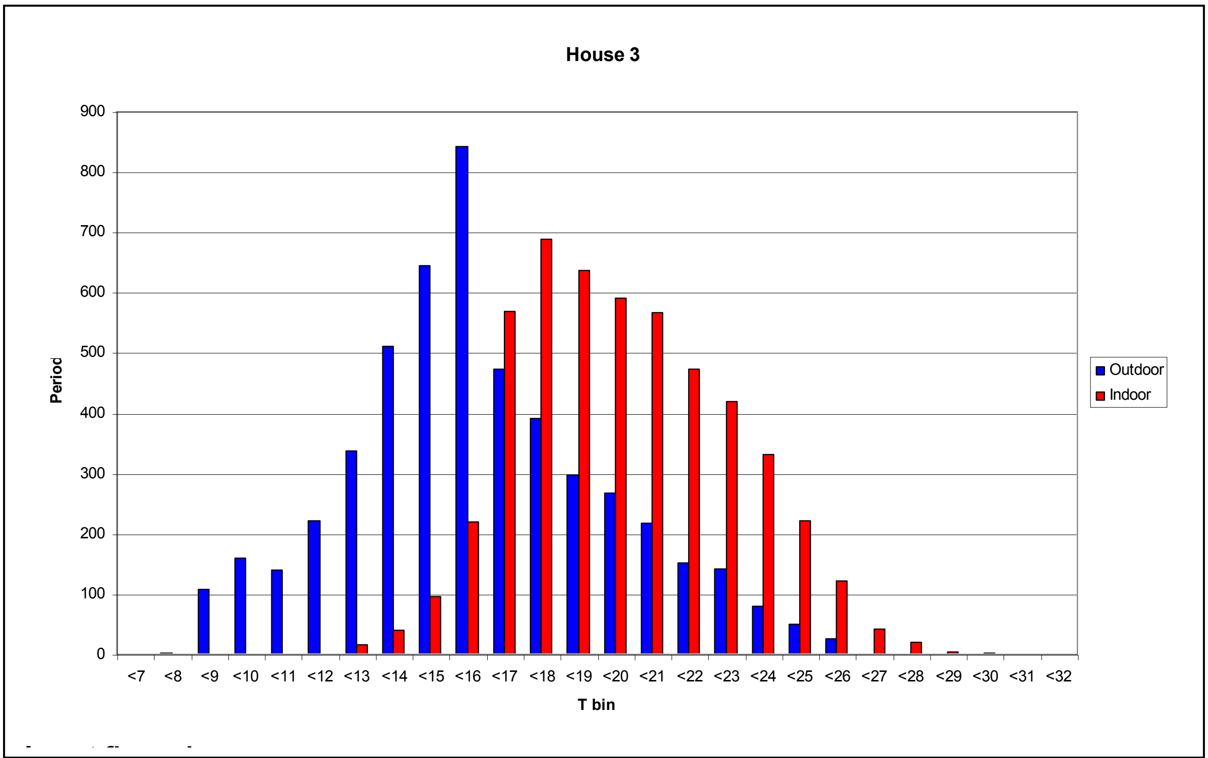


Figure 5: Temperature distribution from March to May 2010, REMP house 3

Miscellaneous end uses

There are up to 130 plug in appliances in a home (average 70): clearly only a minority of these can be directly monitored as part of an end use metering campaign. Some end uses are stored away when not in use, which presents special difficulties for measuring their energy consumption (eg irons and vacuum cleaners). Many of these small miscellaneous appliances probably have very low total energy consumption and many have only one or two simple modes. Some have no or little significant user interaction (eg smoke alarms, alarm systems, PABXs, doorbells). Spot measurements of all potential plug loads and information on whether they are normally connected to mains power assists in understanding number and type of loads in each house. It is also possible to rotate in line meters through a selection of smaller miscellaneous products on a monthly cycle to identify any key uses and issues. More important loads need to be metered for at least several months (where there is no seasonal influence) or a whole year if there is some seasonality.

Individual in line meters should be allocated to major appliances and major energy users. Products with longer cycles and variable energy (washers, dryers, dishwashers) should always be separately metered as these can never be clear identified at the switchboard. End uses that have no user interaction should not be monitored. If lighting is considered to be important, then all plug in lights should be measured. Portable products also present special difficulties to end use monitoring as meters can be disconnected and moved around.

Approach to product classification and data analysis

Plug loads can be broadly categorised as follows:

- Simple products (one mode)
- Discrete mode products (several distinct modes)
- Cycle base products (eg washers and dryers)
- Heating and cooking products (usually thermostat controlled)
- Portable and battery power products
- Household refrigeration products

Most useful analysis output varies by load type (need to know about product measured in all cases)

- Simple products – average power (which is specific to that product only)
- Discrete mode products – average power by mode and percentage (share) time in each mode
- Cycle based products – frequency of use (uses per day/ week/month) plus energy and time per cycle (+ measure variability), off power or other low power mode attributes
- Heating/Cooking – average power and hours use, off power
- Household refrigeration – daily/monthly energy, disaggregated elements
- All products – examine whether there are seasonal affects
- All Products – time of day by hour plus average power (or energy) for each hour, day, month

In a larger study demographic factors could be examined for many of these elements.

User related considerations when monitoring appliances and equipment types are set out in the table below.

Table 3: Key considerations for end use monitoring by appliance type

Product	Portable	User switched	Other user factors	Comment
Clothes washer	No	Yes	Program setting, cold and hot inlet temps, load size	Program determines energy and length, load sensing, inlet temp seasonal
Dishwasher	No	Yes	Program setting, cold inlet temps	Program determines energy and length
Clothes dryer	No	Yes	Load size and final moisture setting	Timer energy use can be erratic
Refrigerators and freezers	No	No	Door openings and food	Ambient temp effect, need 1 minute data
Computer	No	Yes	Power management can reduce during no use	PM rarely implemented, some left on, some servers
Monitor (screen)	No	Yes	Power management can reduce	PM common

Product	Portable	User switched	Other user factors	Comment
			screen saver power	
Laptop	Yes	Yes	Complex – usage and battery charging	PM common
Printers	No	Yes/No	Pages printed	Off, standby, on, some left on
Computer aux	No	No (usually)	None	Usually left on
Switch, router, modem, wireless	No	No (usually)	Usually little change	Advanced PM like EE Ethernet still rare
Cordless phones	No	No	Extended handset use recharge	Base station not portable
Answering machines, PABX, fax, MFD	No	No	Small changes when functioning	Usage rare, usually left on
Audio equipment	No	Yes	Usually small changes in power	Some items may be portable
Televisions	No	Yes	None	Picture can affect power for many types (not user controlled)
Other AV	No	Yes	Usually little change in power	Often left on
Small chargers	Yes	Depends	Depends	Many are left on and charge only occasionally, often many per house, includes mobile phone, electronics
Ovens	No	Yes	Temperature, duration	Cyclic power thermostat, hard wired
Cooktops	No	Yes	Temperature, duration	Simmerstat, hard wired
Microwave	No	Yes	Time selected	
Kettle	No	Yes	Water volume	
Toaster	No	Yes		Setting has minor impact
Small kitchen appliances	Yes	Yes	Time used	Many are unplugged, some cookers are cycle based
Space heaters	No	Yes	Temperature, duration	Mostly cyclic power thermostat, some portable
Space coolers	No	Yes	Temperature, duration	Cyclic power thermostat, hard wired
Water heaters storage	No	No	Volume hot water	Recovery may occur after use
Water heaters instant	No	Yes	Volume and temp of hot water	Startup losses as well
Lighting	No	Yes	None	Some sensing lights not user switched, mostly steady power, plug in not usually portable in practice
Pumps	No	No	Depends on service	Most automatically controlled, water, pressure, pool
Garage door opener	No	Yes	None	Energy per event
Water beds	No	No	None	Internal thermostat, seasonal
Smoke alarms	No	No	None	
Clock radios	No	No	None	Virtually constant
Baby monitors	Yes/No	No	None	Transmitter may be moved

Product	Portable	User switched	Other user factors	Comment
Vacuum cleaners	Yes	Yes	Period used	Difficult as most are portable
Irons	Yes	Yes	Temperature setting	Constant power with thermostat control
Sewing machine	Yes	Yes	Motor use and light	
Fans	Yes/No	Yes	Period used	Some portable, some fixed (hard wired), some with timers
Air filters, fresheners	Yes/No	No		
Personal items	Yes/No	Yes/No	Period used	Many battery charged have constant power, toothbrush, razor, hair etc
Watering controllers, other timers	No	No	Length on (program)	Standby virtually all the time
Tools and garden	Mostly	Yes	Period	Most portable, some with batteries and charging

Notes: All user switched products may have standby or off mode power consumption when connected to the mains, Portable products are those that can be and are often moved in practice. These present difficulties for monitoring as when they are moved they may be connected to different outlets (and circuits) and monitoring equipment that is normally unplugged in not usually feasible. Table only covers electric appliances. Gas and other fuels require special techniques and approaches.

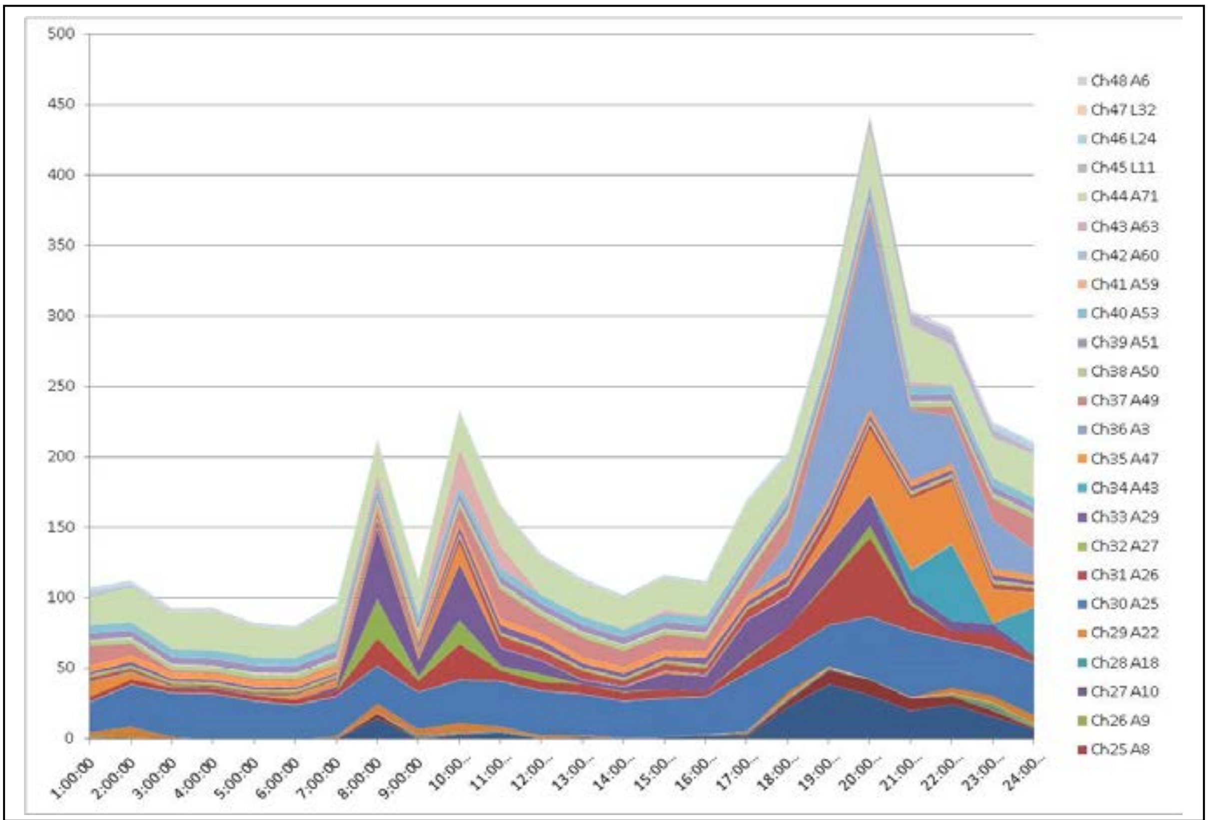


Figure 6: Average time of day power use by appliance, REMP house 5, May 2010

Peak load drivers

Total house monitoring allows not only the frequency, duration and timing of specific peaks to be identified, but the key source of the peak to be identified. This type of data is critical to assess the likely effectiveness of demand response approaches to reduce peak demands during critical events. In Australia, as in many countries, peak electricity loads are driven by air conditioner use on extreme weather days [4]. Data like that shown in Figure 6 is critical to understand the contributors to peak loads.

Key lessons

The monitoring of 5 pilot homes in Melbourne has provided a wide range of key lessons. Some of the most important learnings are listed below.

- In an end use monitoring program, a wide range of products and equipment will be encountered in the field of varied age and varied efficiency.
- While the energy attributes of the products themselves are of some interest, the primary objective is to characterize the user related aspects of energy consumption as far as possible – some of these will have demographic and weather related elements.
- Accurate data on user related aspects can only be obtained through end use measurements. For most appliances and equipment, user related aspect are the most important energy determinant. For refrigerators, ambient temperature (which is indirectly user related) and user related load (openings and food loads) are both important for energy.
- Some products have little change in power over time – mostly small electronic equipment (eg some LAN and network related equipment which is left on, devices like phones and answering machines, security systems etc, which are always on but rarely in a different energy state).
- The energy service being delivered for some products (and therefore efficiency) cannot be practically determined from field data, especially space conditioning equipment.
- For more complex water heaters, the energy service delivered can always be directly metered and this is the most critical parameter to monitor. Tracking energy inputs for complex water heaters is not generally practical in the field (large number of temperature sensors plus detailed solar and other weather related data).
- Real users are highly diverse so energy consumption can vary dramatically from hour to hour and day to day, as well as season to season. Characterising these distributions to enable large scale modelling of the stock should always be a key objective.
- In order to disaggregate user related aspects from other important energy characteristics, good information on each individual product monitored needs to be known – refrigerators (temp power response), clothes washers and dishwashers – expected energy by program (and load size). Spot power measurements of all products is strongly recommended.
- Residual power on each circuit (after dedicated in line meters are removed) provides useful data where the all products and lights are mapped by circuit – power signatures can be used to identify unmetered products where power consumption is fairly steady over time (but need 1 min data or less). Need to correct for parasitic power of in line meters on each circuit.
- Peak loads can be driven by many appliances – 1 min data helps to identify key products of concern – time of use patterns through average days by month and season are important. Some peak loads are weather driven (space conditioning), so these effects and drivers can be established.
- Real users can be difficult – they unplug things and move things around. Need to know the power characteristics of each channel and check that these match periodically.
- Idea of the in use monitoring is to see what people do without unduly influencing their behaviour. So any system needs to be as unintrusive as possible.
- The amount of data is immense – the pilot homes are accumulating 100,000 data points per day per home – need good data processing, cleaning and storage systems (nearly 200m data points collected so far). Continuous data checking is essential.

- Wireless system with automatic upload avoids the need for house visits except where equipment needs servicing.
- Getting homes to participate is hard work – recruitment of suitable homes takes a lot of effort. Many homes are unsuitable due to old wiring, unrepresentative characteristics, problems with permission and access, renovations and the like.
- It is almost essential to access potential candidate houses through a utility or similar organisation with a large potential customer base.
- The problem in any sampling is to minimise sample bias, as anyone who is interested and willing enough to participate in a study, will already be biased.
- The creation of a larger study will require some statistical thought (on experimental design) before/during house recruitment/selection.
- Although it is somewhat against the 'random sampling' approach, in economic terms, it is not practical to have monitored households that are geographically dispersed over a wide area. Households should be located within a practical radius (eg 50km) and a technician to deal with any problems should be local (ie not require air travel or hours of drive time), otherwise costs may be prohibitive
- Even if everything goes as planned, occasional site visits will still be necessary for:
    - Reprogramming
    - Installation checks if a meter stops working
    - Reallocation of meters with appliance purchase or retirement
    - Fixing small problems – provision of in-line switches for convenience, redressing meter organisation, dealing with radio freq noise or interference, battery replacement.
- Despite our best efforts, householders will do strange things – you have to be prepared for this!
- Despite instructions some households turn appliances off at the power outlet or remove them.
- Sometimes appliances are unplugged from in-line meters and plugged into different (nearby) meters – this can be very confusing (using only data uploads). Eg – what is supposed to be a light is now a TV, what was a set top box, is now a DVD etc.
- Sometimes meters are moved when an appliance is moved – they then appear on a different circuit (which affects residual calculations).
- Automatic checks on the expected power profile/signature of each individual appliance channel will help to flag if products have been moved. Tracking meters on the same product that are moved to different circuits is more difficult, but examining power residuals for every circuit (based on the in line meters that should be present) can flag issues.
- Avoid renovations – makes monitoring difficult to impossible and is unrepresentative and generally a waste of time.
- Collecting real data from real houses provides great insights into user behaviour and habits
- Many of the main problems can be addressed through smart software, data checking routines and good preparation (anticipation of issues).
- Hardware has mostly been reliable and appears to be accurate – some fine tuning is always required in such complex systems.

Monitoring of the 5 pilot homes has provided a wealth of end use data that can be mined for years to come. A proposal to monitor a larger sample of homes is currently being developed. An expanded monitoring program, if it proceeds, would put Australia at the forefront of end use measurement in the residential sector.

References

[1] REMP 2010. *Technical Workshop for the Pilot Residential Energy Monitoring Program* (REMP), Department of Climate Change and Energy Efficiency, 4 June 2010, Melbourne. Papers and presentations are available from http://www.energyrating.gov.au/2010-06-remp.html

[2] Energy Efficient Strategies, *2005 Intrusive Residential Standby Survey Report*, Report 2006/02, prepared for the Australian Greenhouse Office. Available from www.energyrating.gov.au in the electronic library.

[3] Harrington L. and Kleverlaan P., *Quantification of residential standby power consumption in Australia*. April 2001, prepared for the Australian Greenhouse Office. Available from www.energyrating.gov.au in the electronic library.

[4] Energy Efficient Strategies, *Electrical Peak Load Analysis Victoria 1999 – 2003,* prepared for the Victorian Energy Networks Corporation (VENCORP) and the Australian Greenhouse Office, January 2005. Available from www.energyrating.gov.au in the electronic library.

[5] Energy Efficient Strategies, *Energy Use in the Australian Residential Sector 1986-2020,* prepared for the Department of the Environment, Water, Heritage and the Arts, June 2008. Available from www.energyrating.gov.au in the electronic library.

End-use demand at Norwegian household customers

Hanne Sæle, Nicolai Feilberg

SINTEF Energy Research

Abstract

Today there is an increasing focus on challenges related to climate-changes and security of energy supply. In the SET-Plan from EU a binding target is specified for 2020 to reduce the EU global primary energy use by 20 %, compared to a normal development [1]. Energy efficiency in energy conversion, supply and end-use is the short cut to a strengthened energy balance, but knowledge concerning the demand is crucial to understand how to affect it.

This paper presents results from the research project “Electricity Demand Knowledge” (ElDeK) – focusing on how and when the households are using electricity. The objective of the project is to contribute with increased knowledge concerning the electricity demand for different electrical appliances in households and also the total electricity consumption for a household. This includes knowledge concerning both the total energy demand [kWh] and power demand [kWh/h] for the different customers and end-uses.

The results show that the largest part of electricity use is related to heating. The total demand for an average work day is varying – with a peak in the morning (hour 9) and in the afternoon (hour 17-22). The peak in the morning is coinciding with the peak hour in the Nordic power system.

Increased knowledge regarding the electricity consumption (how and when) will be an important input when different measures for energy efficiency and demand response are evaluated. Important parameters are how the different appliances are used, the daily routines of the persons and the degree of flexibility of the different end-uses.

Introduction

Increased share of intermittent renewable electricity generation and peak load capacity required for relatively few hours have increased the focus on demand side participation. Demand side management programs are expanding in response to high load growth and the increasing cost and time required bringing new generation into service [2].

The traditional approach when operating the power system has been to supply all the consumption at any time. However, after restructuring and deregulation of the electricity industry, the new philosophy states that the system will be most efficient if the differences between peak and low load periods are kept as small as possible [3]. An important benefit of demand response is avoided construction of expensive power plants to serve the peaks that occur for just a few hours per year; demand response offers the needed flexibility at relatively low cost [4]. Knowledge about the electricity consumption is important input when evaluating possible sources for demand response.

This paper presents the results from the first part of the metering campaign performed at Norwegian households. The focus is on the end-use demand compared to the total demand – and also an evaluation concerning how some demographic data may influence the electricity demand – in total and for some electrical appliances.

Background

To explain the changes in electricity demand, there is a need to have sufficient amount of data concerning electricity demand and knowledge of the customers’ reaction on changed framework and market conditions. Lack of data and lack of understanding of observed changes in demand make it difficult to perform sufficient energy scenarios. A good mapping of today’s situation is an important basis for efficient reduction of energy demand, and knowledge concerning customers is important to develop instruments for long-term changes in electricity demand behaviour. A large amount of data is needed for this purpose, and from previous research projects it is experienced that data collection (referred to metered data of electricity demand) is a difficult and costly task – especially for end-use demand.

There are about 2.6 millions metering points in Norway [5], and all customers with a consumption larger than 100.000 kWh/year have hourly metering of their consumption. Additionally, some smaller households have hourly metering of their demand. In total, about 60 % of the total electricity consumption in Norway is hourly metered.

The process for full scale installation of Smart metering technology in Norway is ongoing. The Norwegian Water Resources and Energy Directorate (NVE) has previously indicated that this should be performed within 2018. Some proposed functionality requirements are hourly metering, including the possibility to change the meter frequency at short notice. In January 2011 a press release from the Ministry of Petroleum and Energy promoted that the Norwegian regulator should submit a proposal for earlier installation of Smart metering technology in Central Norway (2013). In addition, the final deadline for the rest of the country should be expedited to the end of 2016 [6]. This request will be included in the discussion document concerning functional requirements for the smart metering technology expected in February 2011.

The large amount of data generated from the full scale installation of smart metering technology can be an important source for increased knowledge about electricity consumption – independent of the time resolution chosen for metering. By structuring these data it will be possible to use this information for future research tasks.

The REMODECE project (2006-2008)[1] analysed metered data to calculate the end-use demand for several households from different European countries [7]. Statistical analysis of the metered data was used to achieve values adjusted according to the total population of the different countries. For Norway about 79% of the electricity in an average household was used for space heating and heating of tap water, depending on the outdoor temperature [8]. (This value included also the electricity consumption of some smaller end-uses not included in the metering campaign.) The percent distribution for different electrical appliances in Norway for 2006/2007 is presented in Figure 1.

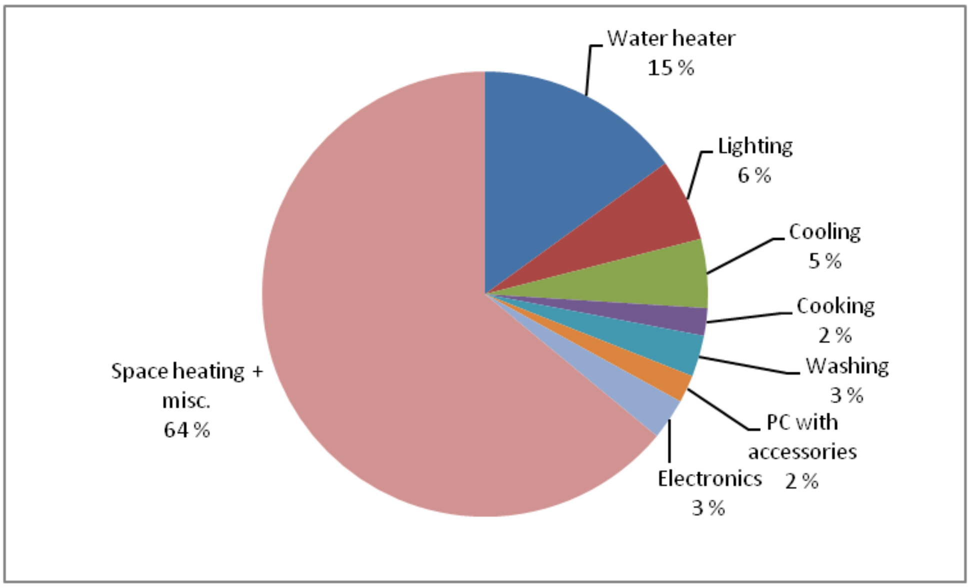


Figure 1 Percent share of electrical end-uses in Norway (2006/2007) [8]

---

[1] REMODECE = Residential Monitoring of Decrease Energy Use and Carbon Emissions in Europe. EU-project within the Intelligent Energy for Europe Programme of the European Community (contract no. EIE/05/124/S12.419657).

Research project "Electricity Demand Knowledge" (ElDeK)

The main objective of the ElDeK[2] project (2009-2012) at SINTEF Energy Research is to increase the knowledge concerning the electricity demand for different groups of end-users such as household customers. This includes both the total energy demand [kWh] and power demand [kWh/h] of different customer types and end-uses.

The project is a part of the RENERGI program at the Norwegian Research Council. The project is funded by the Norwegian Research Council, Enova SF[3] and the Norwegian Water Resources and Energy Directorate[4].

Dedicated metering equipment will be used to meter the electricity consumption for different electrical appliances such as washing machines, dishwashers, cookers, freezers, lightings, TVs, PCs/laptops etc. This metering is performed with one-minute intervals for a metering period of approx. 4 weeks per customer. The customers participating in this project have already installed technology for hourly metering of their total electricity consumption. The total consumption will be metered for one year per customer. Both metering data for end-use demand and total demand will be analyzed. Demographic data will also be collected from the participating customers, and included in the analyses.

The work within the ElDeK project will be based on results and experiences from the REMODECE project. Within the REMODECE project end-uses in the household sector were metered, but for some appliances the amount of data available is too scarce to assure statistical significance. Metering of end-uses is costly, as a metering device must be attached to every appliance to be metered. The benefit is that the metered data gives exact information concerning the end-use demand.

Metering campaigns

Metering of end-use demand is performed at households with installed technology for hourly metering of the consumption. In Norway, the Distribution System operators (DSOs) are responsible for metering the electricity consumption. In the ElDeK project metering has so far been carried out by three DSOs *FosenKraft*, *SFE* and *Hafslund*. This paper presents metering results from FosenKraft and SFE.

The DSOs have been responsible for contacting the customers and gathering information about which appliances that can be metered. 5-10 appliances per household are metered for a period of approx. 4 weeks. SINTEF Energy Research prepares the metering equipment and sends it to the customers via ordinary mail. The customers install the metering equipment in their home. After the metering period is finished, the customers remove the metering equipment and send it back to SINTEF Energy Research together with a questionnaire regarding use of energy and demographic information. Pictures of used metering technology are presented in Figure 2.

---

[2] www.sintef.no/eldek

[3] www.enova.no

[4] http://www.nve.no/en/

Figure 2 Power Detective - plugs for metering of end-use demand. The rightmost picture shows metering of the demand for an electric cooker [9]

Challenges concerning the metering are to secure a sufficient amount of metering objects from a significant sample and metering periods of a sufficient length. The metering objects should be a random sample and the customers and their electricity consumption should not be affected by the metering.

The metering technology used in the project does not support remote reading. The meter data is stored on a memory chip located in a central unit. Therefore, the duration of the metering period is dependent on the storage capacity of the memory chip.

Results

The results presented in this paper are the first results from the ElDeK project. Customer surveys, metering of end-use demand and total electricity consumption for households customers of FosenKraft and SFE are discussed. The results will be updated with more meter data during the ElDeK project.

Customer surveys

All customers with end-use metering were asked to answer a survey with questions on demographic data and energy use. In this chapter different characteristics regarding the selected households at FosenKraft and SFE are presented. In total 32 customers participated from these two DSOs.

According to the survey, all customers lived in single-family houses. 63% of the buildings were built before 1990 and the rest (37%) was built in 1990 or later. The average building year was 1981. 45% of the households had less than or equal to 150 m^2 living space, and the rest (55%) had more than 150 m^2. The average living space was 168,5 m^2.

The customers were also asked about the number of persons within different age categories. Based on this the different families have been structured as “No kids” (1-2 grown-up persons, 25% of the households), “Families” (More than 2 persons, 66% of the households) and “Retired” (Older than 62 years, 9% of the households).

The customers were asked about sources for space heating in their homes. Several answers were possible per customer. The result is presented in Figure 3.

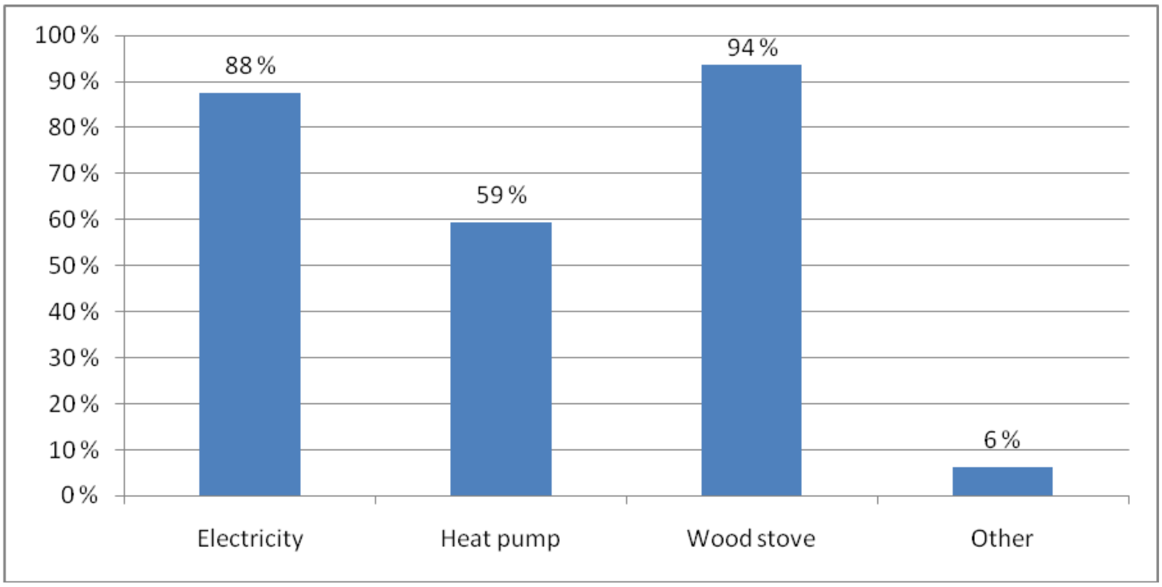


Figure 3 Sources for space heating

Wood stove and electricity were the main appliances for space heating, with 94% and 88% respectively. *Electricity heating* includes panel heaters and electrical heater cables for floor or roof heating. 59% of the customers had installed heat pumps. The “Other” category includes electrical boiler for waterborne space heating systems and ground heat.

Other results from the survey were:

- 97% of the customers used electricity for water heating (electrical boiler).
- 38% of the households had installed an energy saving shower, to reduce the use of hot water.
- 81% of the households had heating cables in the floor or the roof, in average used for heating of 39 m^2.
- 66% of the customers used to have the heating cables on permanently.

The education level for the main group was upper secondary school (44%). The education levels for the rest were mainly university until 4 years (28%) and more than 4 years (22%). 6% had primary school as the education level.

34,4% of the households had a total gross income less than 62.500 Euros/year, and 59,4% had a gross income larger than 62.500 Euros/year. 6,2% did not want to answer this question.

Analysing meter data

In the project the electricity consumption for different appliances was metered every minute and the total electricity consumption was metered on an hourly basis. The meter data are analysed according to the daily use of electricity and the total use of electricity per year for the different end-uses.

The end-use demand and total electricity demand for an average household customer for a typical work day are presented in Figure 4. The results are based on metering performed at the 32 customers from FosenKraft and SFE. The figure shows that there is a large amount of electricity used for space heating. As in REMODECE, this category also includes different smaller appliances not metered.

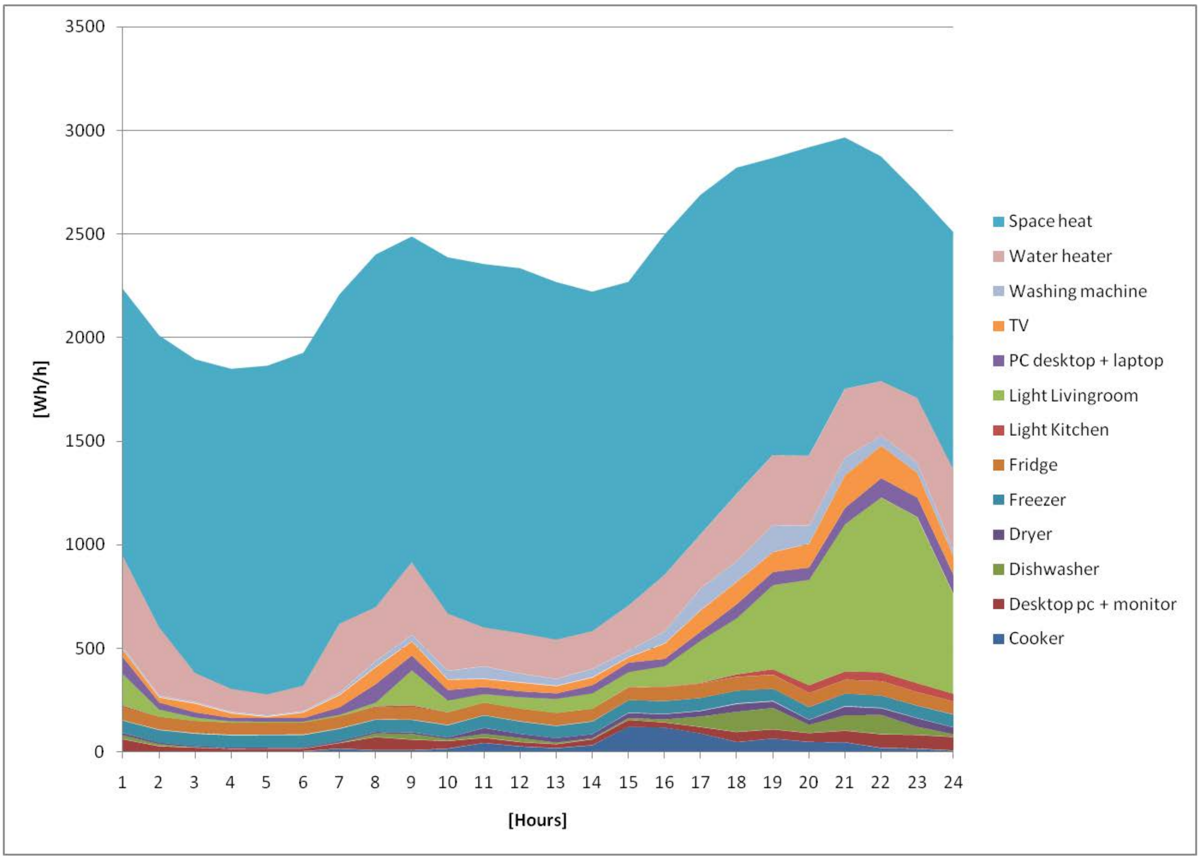


Figure 4 Daily use of electricity in total and for different end-use demands

The total consumption of electricity during the day has a peak in the morning (hour 9) and in the afternoon/evening (from hour 15 to 22). The peak load in the morning is coincident with the peak load of the electrical water heater, which is coinciding with the peak hour in the Nordic power system [10]. For lighting in the living room, the main consumption is in the afternoon/evening, from hour 16 to 24. The main consumption for the cooker is in hour 15 to 17, and for the dishwasher it is in hour 17 and outwards. This confirms the natural routine of washing up the dishes after the dinner. There is not much electricity metered for lighting in the kitchen, and the figure shows that this is mainly in use in the hour 19 to 24. The washing machine, PC and TV is in use during the whole day, but mainly in the afternoon (hour 17-20).

Based on the meter data the total yearly electricity consumption is calculated for a typical household, divided for different end-use demands (See Figure 5). This figure is more detailed than Figure 1, because the electricity consumption for different appliances is presented. Figure 1 shows the electricity demand for different categories of demand. The share of consumption for fridges (2,6%) and freezers (2,5%) for instance is specified in Figure 5 while this is presented as “Cooling” (5%) in Figure 1.

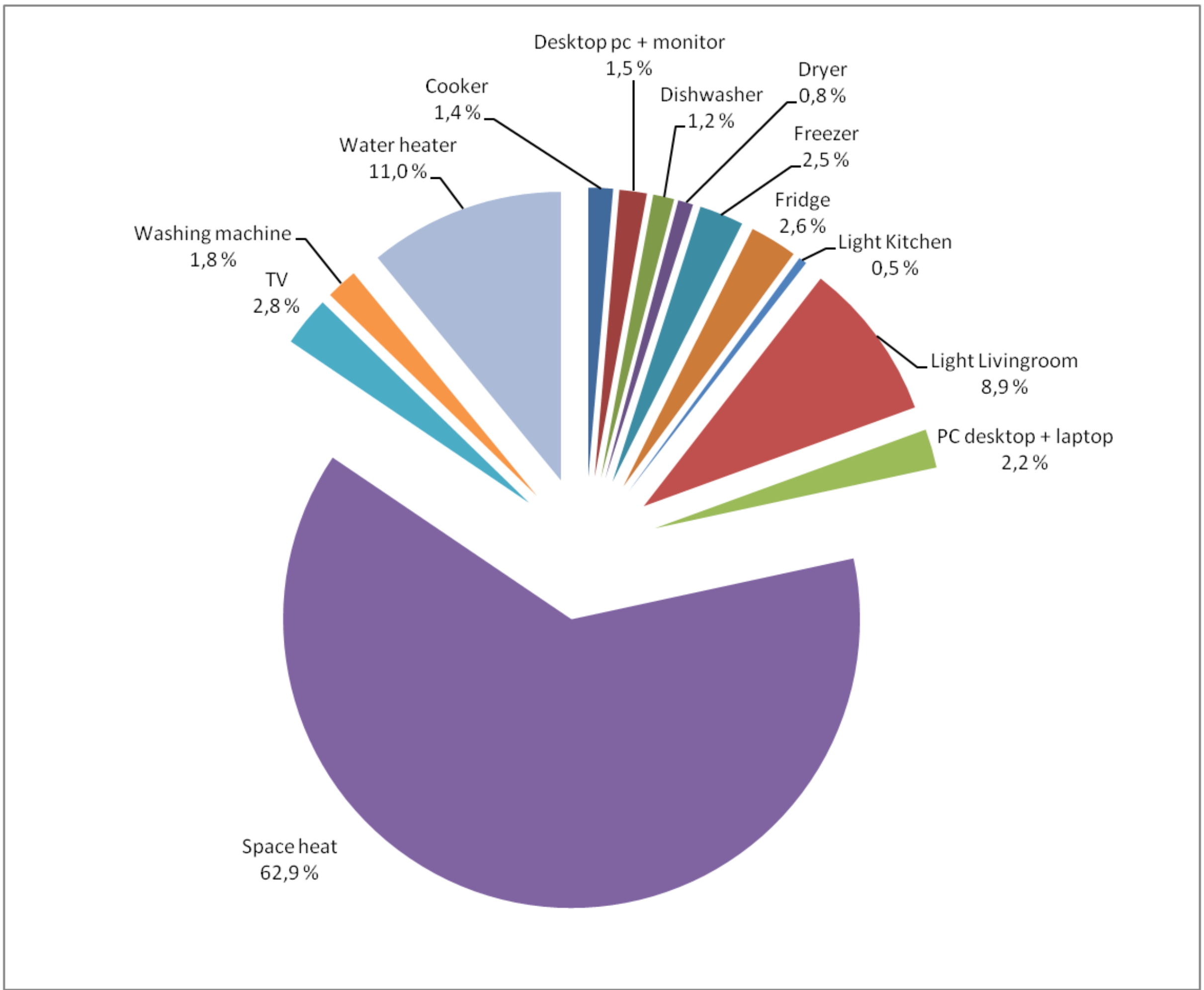


Figure 5 Annual consumption for different end-uses

The largest consumption group is space heating (incl. smaller appliances not metered), with 62,9% of the total consumption. Water heating (11,0%) and lighting in living room (8,9%) are the second and third largest groups. There is some insecurity regarding the results for light in living room, because the metering have mainly been performed during the winter – when the need for lighting is largest in Norway, compared to the rest of the year.

These results show that the consumption groups that are using most electricity are related to heating – both space heating and the heating of tap water, and therefore these groups have highest focus when discussing energy efficiency in Norway.

Analysing meter data

The electricity consumption for the households is related to different variables as for example the building year, the living space, the number of persons in the household, the yearly gross income for the family and the different sources used for space heating. Some relations between these variables will be presented, based on analyses of the customer survey and the meter data (in total and for different end-uses).

Relations between average yearly consumption of electricity, building year and the living space are presented in Figure 6. The figure shows that for the test group (32 households in total) 15 of the households have buildings equal or less than 150 m^2, and among these 11 buildings (34%) were built before 1990 and 4 households (13%) were built in 1990 or later. 17 of the households have buildings larger than 150 m^2, and among these 9 buildings (28%) were built before 1990 and 8 buildings (25%) were built in 1990 or later.

Based on the meter data achieved, the average yearly electricity consumption was larger for the households with buildings equal or less than 150 m^2, compared to the larger buildings (> 150 m^2). One explanation might be that the largest buildings are also the newest, and therefore also the most energy efficient ones (New building regulations were introduced in Norway in 1996). This topic will be further evaluated when more meter data is available.

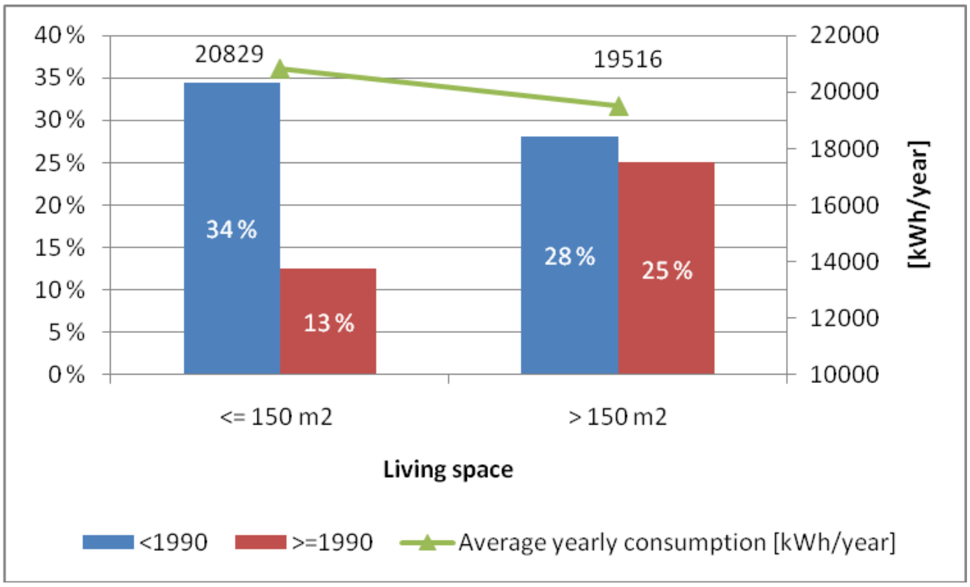


Figure 6 Average yearly electricity consumption, living space and building year

The relations between average yearly electricity consumption and total gross income for the family are presented in Figure 7. The gross income is divided in customers with more or less than 62.500 Euros/year. The figure shows that the household customers with the highest yearly average consumption are mainly the customers with the highest income and the largest buildings. 38% of the customers have more than 62.500 Euros/year in gross income and a living space larger than 150 m^2. 25% of the customers have a gross income less than 62.500 Euros/year and a living space less than or equal to 150 m^2. (No households have less gross income than 31.250 Euros/year.)

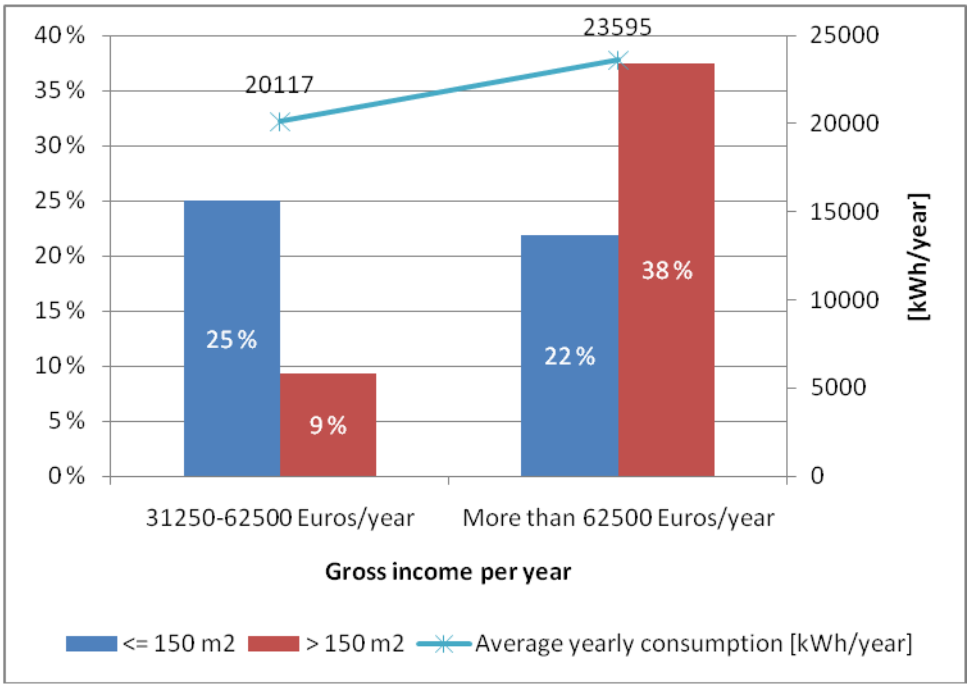
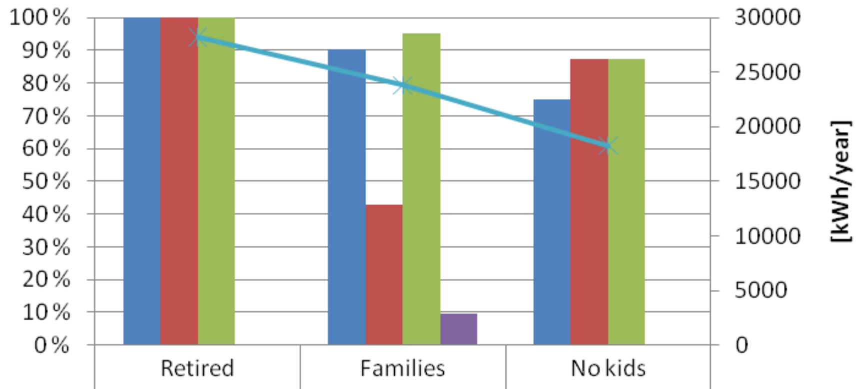


Figure 7 Average yearly electricity consumption, living space and gross income

The relations between average yearly consumption of electricity, family category and the heating source in the building are presented in Figure 8. The family category presented is “Retired” (Older than 62 years), “Families” (More than 2 persons) and “No kids” (1-2 persons). For all family categories there were a large amount of electricity and wood stove used for space heating.



	Retired	Families	No kids
Electricity	100 %	90 %	75 %
Heat pump	100 %	43 %	88 %
Wood stove	100 %	95 %	88 %
Other	0 %	10 %	0 %
Average yearly consumption [kWh/year]	28217	23798	18274

Figure 8 Average yearly electricity consumption, family category and heating sources

Only 3 households (9%) are represented in the category “Retired”, and all of these are using electricity, wood stove and heat pump for space heating. The average total electricity consumption in this category is larger than for the other two groups. This seems a bit strange, since this group represents families with only 1-2 persons, but on the other side these persons are more often at home during daytime. The average yearly consumption for families with children is higher than for the families with no kids. This sounds reasonable since families with kids consist of more persons, and thereby more often use of different electrical appliances (for example the washing machine) and a larger living space to heat. (The average living space for “Families” is 183,0 m^2, while the average living space for the category “No kids” is 146,9 m^2.) In average, the “Families” category has older buildings than the category “No kids”, with average building years of 1979 and 1988 respectively.

Discussions and Further work

This paper presents results from the ElDeK project, focusing on what the households are using electricity for and how electricity is used in total and for different end-uses. The results are based on metering every minutes of the electricity consumption for different end-uses, hourly metering of the total consumption for the household and a customer survey. 5-10 end-uses were metered at each household.

The results show that the consumption groups using most electricity are related to heating (space heating and the heating of tap water), and therefore these groups have highest focus when discussing energy efficiency in Norway. These results confirm the previous results from the REMODECE project.

The total demand for an average day is varying – with a peak in the morning (hour 9) and in the afternoon (hour 17-22). The first peak occurs after the persons get up in the morning, and the second peak occurs when the persons come back home after school/job/etc.

Increased knowledge regarding the electricity consumption (how and when) will be an important input when different measures for energy efficiency and demand response should be evaluated. Important parameters are how the different appliances are used, the daily routines of the persons and the degree of flexibility of the demand.

The results in this paper are based on metering performed at two DSOs. Several DSOs will participate in the project, and the results will be further confirmed when the amount of data increase.

References

[1] “A European Strategic Energy Technology Plan (SET-Plan). Communication from the Commission to the Council, The European Parliament, The European Economic and Social Committee and the Committee of the Regions”, COM(2007) 723 final

[2] Federal Energy Regulatory Commission, Assessment of Demand Response & Advanced Metering. Staff Report, 2008.

[3] M. H. Albadi, and E. F. El-Saadany, “A summary of demand response in electricity markets,” Electric Power Systems Research, vol. 78, no. 11, pp. 1989-1996, 2008.

[4] U.S. Department of Energy, Benefits of Demand Response in Electricity Markets and Recommendations for achieving them. A report to the United States Congress. Pursuant to Section 1252 of the Energy Policy Act of 2005, U.S. Department of Energy, 2006.

[5] ”About the use of new technology for metering and communication” (In Norwegian, “Om bruk av nye teknologier for måling og kommunikasjon”), NVE paper 07.06.2007, www.nve.no

[6] ”All-out effort for smart metering” (In Norwegian, ”Tar krafttak for automatisk strømmåling (AMS)”). Press release from Ministry of Petroleum and Energy, 12. January 2011

[7] “Residential Monitoring to Decrease Energy Us e and carbon Emissions in Europe”, A. Almeida, P. Fonseca, B. Scholmann, N. Feilberg, EEDAL 2006

[8] “D10 - Analysis of Monitoring Campaign in Norway”, Bjørn Grinden, Nicolai Feilberg, EIE/05/124/SI2.419657, http://www.isr.uc.pt/~remodece/

[9] “State-of-the-art. Projects for estimating the electricity end-use demand”, TR A6999, Hanne Sæle, Eva Rosenberg, Nicolai Feilberg, September 2010, SINTEF Energy Research, http://www.sintef.no/Projectweb/ElDeK/Publications/

[10] “Market based solutions for increased flexibility in electricity consumption”, O. S. Grande, and H. Sæle, in Conference on Security of Supply in Competitive Electricity Markets - Market Design 2005, Stockholm, Sweden, 2005, pp. 55-60.

The European market for energy efficiency services in the residential sector and the effects of existing energy efficiency policies on its development

Nicola Labanca

end –use Efficiency Research Group (eERG)
Politecnico di Milano, Dipartimento di Energia, Milano Italy

Lorenzo Pagliano

end –use Efficiency Research Group (eERG)
Politecnico di Milano, Dipartimento di Energia, Milano Italy

Wolfgang Irrek

Hochschule Ruhr West, Bottrop, Germany

Maike Bunse

Wuppertal Institut für Klima, Umwelt, Energie GmbH, Wuppertal, Germany

Piet Boonekamp and Paul Vethman

ECN, Petten, The Netherlands

Bruno Duplessis

Centre for Energy and Processes – Mines Paris, Paris, France

Vladimir Sochor

SEVEn, Prague, Czech Republic

Keywords

Energy end-use efficiency, energy efficiency services, policies and measures, energy service companies, energy distributors, distribution system operators, retail energy sales companies, markets for energy efficiency services.

Abstract

A main objective of the Energy Service Directive (ESD) is to stimulate the market for energy efficiency services (EES) and for the delivery of other energy efficiency improvement measures to final consumers. In order to achieve this objective, the ESD gives a special role to energy companies. On the other hand, there are energy service companies (ESCOs) and further actors ready to expand their business in the field of energy efficiency services. Against this background, it is important to know about the status and barriers of the markets of EES in Europe, how and to which extent existing energy efficiency policies foster or hinder EES market development, and how energy efficiency policies should be designed and implemented to stimulate this market. Since 2009 the IEE project ChangeBest is committed to assisting energy companies and ESCOs in entering the EES business, starting with an empirical analysis of the existing EES markets and the respective economic and policy frameworks.

The paper will discuss the effects of the existing energy efficiency policies on the provision of EES for the residential sector in the EU as analysed in the ChangeBest project and present the preliminary project conclusions and recommendations for the formulation and implementation of energy efficiency

policies that can stimulate EES provision in this sector. This will be done firstly by presenting an overview of the development status of the EES markets in the countries covered by the ChangeBest project and by discussing how existing national and EU policy measures positively or negatively influence the demand for, and supply of, EES for the residential sector in these countries. Then existing EES market potentials in the residential sector will be briefly discussed and the main preliminary ChangeBest project conclusions and recommendations on the formulation of policy measures which are most suitable for the exploitation of these potentials will be presented.

Introduction

Since July 2009 the IEE[1] project “Promoting the development of an energy efficiency service market” (ChangeBest) is supporting the implementation of the Energy Service Directive (ESD) by assisting energy companies and ESCOs in entering the B2B and B2C market for EES, contributing to the development of the EES market and demonstrating good practice in implementing the ESD.

Among others things, ChangeBest project activities have so far produced a cross-country analysis [1] of the energy efficiency business in the 18 countries and regions participating in the ChangeBest project[2], an analysis of the positive or negative effects of existing policy measures on the provision of EES [2] and an analysis of the potential market volume for EES in the EU [3].

This paper summarises the results and conclusions achieved by these analyses that can be referred to the residential sector.

The cross-country analysis performed has been based on the 18 country reports on the EES markets’ development. They have been produced by the ChangeBest consortium in the countries by consultation of existing literature and conducting interviews with a number of national experts. One of the main objectives of this analysis has been highlighting similarities and differences in the national EES markets. This objective has been achieved first of all by making a qualitative comparison of the different national framework conditions (e.g. national legislations, status of the national economies, degree of energy market liberalisation, energy prices, etc.) and of the EES provider types existing in each country. Then the possible relationships that have or can be established among the EES market players acting in the various countries, the existing EES market offer for the various customer groups and the positioning of ESCOs and energy companies in the different demand sectors have been compared.

The effects of existing policy measures on EES markets have been studied by developing an analysis structure that describes in general how policy measures stimulate energy savings and how they can influence the demand for, and supply of, EES in EU countries.

The potential market volume for EES in the EU has been estimated based on existing studies that refer to the economic and technical potential of energy savings in the residential sector and on technical material collected by the project partners. The energy savings potentials have been priced with energy tariffs for energy end-users in order to provide an estimate of the market volume available for future possible activities in the field of EES.

In the following paper sections we firstly present an overview of the development status of the EES markets in the countries covered by the ChangeBest project. Then we discuss how existing national and EU policy measures positively or negatively influence the demand for, and supply of, EES for the residential sector in these countries. Finally we briefly discuss existing EES market potentials in the residential sector and present the main preliminary ChangeBest project conclusions and recommendations on the formulation of policy measures which are most suitable for the exploitation of these potentials.

[1] Programme Intelligent Energy Europe of the European Commission: http://ec.europa.eu/energy/intelligent/index_en.html (Grant Agreement No. IEE/08/434/SI2.528383),

[2] Germany, Denmark, Flanders, Sweden, The Netherlands, Austria, France, Italy, Czech Republic, Portugal, Estonia, Latvia, Slovakia, Slovenia, Estonia, Bulgaria, Greece, Poland

Terminology

The European standard on Energy Efficiency Services [4] defines EES as an agreed task or tasks, designed to lead to an energy efficiency improvement and other agreed performance criteria. The standard also requires that EES include an energy audit as well as identification, selection and implementation of actions and verification. Moreover, a documented description of the proposed or agreed framework for the actions and the follow-up procedure has to be provided. Finally, the improvement of energy efficiency has to be measured and verified over a contractually defined period of time through contractually agreed methods. The energy efficiency improvement (EEI) can be of a technical nature (i.e. replacing or improvement of energy systems), organisational nature (better use of technology) or behavioural nature (changing daily energy use). This is the definition of EES also adopted in the framework of ChangeBest and in the present paper.

A distinction is made as to EES activity types that are also indicated as EES value chain stages or partial services connected to EES.

In particular the following types of activities (or EES value chain stages, or partial services connected to EES) are distinguished: (1) awareness raising, (2) information and advice, (3) identification of measures, (4) technical planning, (5) financing and subsidies, (6) implementation (operation and or supervision), (7) optimization of technical operation, and (8) measurement and verification of savings.

As to providers of EES, an EES provider will be defined as any entity that delivers EES. Therefore ESCOs, energy companies or any kind of company (either independent or subsidiary of other companies, either focusing its business on EES or not) will be referred as EES providers in so far as they deliver EES.

Overview of the development status of the EES markets for the residential sector and their market players in 18 EU countries

Despite the high economic energy saving potential of the residential sector (partly having a reasonable investment payback time)[3], the development stage of the EES market in this sector in the countries analysed is on average ranked at the lowest level with respect to the other sectors. Given the existing market conditions and barriers, experts interviewed appear generally quite sceptic about the possibility of a real and significant development of the EES market in the residential sector in the near future. According to the experts and researchers participating in the ChangeBest project, besides sector cross-cutting barriers to the development of an EES market (e.g. level of energy prices, long investment payback periods, lack of information and awareness, lack of appropriate forms of finance) there are indeed specific barriers which make a large scale application of the EES concept in the residential sector on commercial bases much more difficult than e.g. in the industry or public/service sectors. These barriers are:

1. The particularly high transaction costs for EES providers relative to the small amount of energy costs and thus potential costs savings per single EES supplied. In this respect, initiatives aiming at creating district community groups and pooling together a number of buildings to implement energy efficiency improvement measures could be highly beneficial.

2. The high fragmentation of the mass market making standardised EES necessary. A standardised inspection and advice, as part of the energy labelling of dwellings to be sold or rented is often seen as a potentially effective way to partially solve the issue. Moreover in some countries analysed (e.g. Bulgaria, Slovakia, Latvia) the huge amount of existing prefabricated multifamily buildings constructed between 1960 and 1990 and in need of refurbishment represents a very interesting opportunity given the possibility of providing highly standardised EES on a large scale.

3. The so-called landlord/tenant dilemma due to the fact that, although the tenant basically has an interest to reach energy savings through EEI actions, the landlord typically receives no benefits from these investments or can hardly pass on investment costs to the tenant. In this respect the legal requirement that the landlord of a multifamily building is allowed to pass on EEI action investment costs to tenants only if all tenants agree on this investment is an important barrier to EES market development in some countries.

[3] See the paper section dedicated to EES market potentials

4. The decision processes existing in multi-apartment buildings (which usually represent the most interesting investments for EES suppliers and financers) where only the general assembly of apartment owners can take decisions about building management including possible EES implementation. Typically at least one half of the apartment owners directly or indirectly affected by EES implementation must agree on this implementation in order to take any legally binding decision.

5. The fact that the energy consumption in the residential sector is much more correlated to individual needs and behaviours than in other sectors[4]. This can make it particularly difficult to define a consumption baseline and induces high risks when setting energy saving guarantees. Moreover, individual energy consumption meters are often lacking in multi apartment buildings impeding EE investment decisions by single households.

6. Difficulty for potential EES customers to get oriented among existing EES offers also partially due to the difficulty in understanding the ESCO model and the EES financing and contract as well as to the lack of information on the availability of these services. Terms like energy services and EES are sometimes used for services without the clear aim of improving energy efficiency. A European standardisation process has been initiated and it remains to be seen how this will shape the understanding of the terms and ultimately influence the market. Also standard financing and contracting options are being developed in several countries, but customers' understanding of these options remains low. In this respect market actors should be clearly guided to use correctly and fairly the terms and avoid misleading information to customers.

7. The lack of credibility on EES providers also partially due to the often lacking legal framework for the accreditation of EES providers. In addition, because of some bad experiences (poor quality services), households are partly sceptical regarding the EES providers and their offers. In this respect a credible certification system for ESCOs would be very helpful.

8. The fear to become too much dependent on the EES contractor and that the service offered would be more expensive than if the energy efficiency improvement were realised autonomously.

9. The present economic crisis and related economic and political uncertainties.

10. The scarce or difficult accessibility of public subsidies or incentives for EES implementation.

A summary about the development status of the EES markets in the residential sector for ESCOs and energy companies operating in the countries analysed is given in the table 1 below.

Table 1: EES market development status in the residential sector by EES provider in the countries considered

Legenda**:** 1=very well developed; 2=well developed; 3=emerging; 4=not well developed; 5=not existent; empty=unknown
ES = ESCOs; EC = Energy Companies

DE		DK		BE		SE		NL		AT		FR		IT		CZ		PT		ES		LV		SK		SL		EE		BG		EL		PL	
ES[1]	EC	ES	EC	ES[2]	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC	ES	EC
4	2		2	5	2	4-5	4-5	3	5	4	3	3-4	1	3	3	5	5	5	5			3	5	3	3	3	3		5	4	5	5	5	3	5

[1] Not including totally public EES providers like public energy agencies or NGOs

[2] Focus on EPC-contracts

As also showed by table 1, the analysis performed indicates that, in general, the EES market for ESCOs is less developed than the energy company EES market. Whereas the EES market for ESCOs appears in general as more developed than the EES market generated by energy companies in other demand sectors, the typically smaller projects implemented in the residential sector are

[4] Large scale installation of smart meters may partially contribute to overcome this barrier. For example in Italy almost all households are now equipped with electricity meters endowed of remote reading capabilities. The issue is how to make all this information readily available also to energy end-users and ESCOs for verification of the energy savings.

offered especially by retail energy sale companies or energy distributors, often to increase customers' loyalty or to comply with a possible energy saving obligation in place in the country where they operate.

In the surveyed countries or regions where the EES market in the residential sector has been depicted as well developed (i.e. Germany, Denmark, Flanders, France) the EES providers are mostly energy companies. In Germany, energy companies offer EES mainly addressing EEI actions concerning space and water heating, insulation and air conditioning. Such full EES are mostly offered to the housing industry, where a number of apartments or even houses can be covered[5]. In addition, there are heat supply services for single households (house owners) that include energy efficiency improvements of the heating system. Moreover there are some governmental programmes supporting energy agencies, some NGOs and other market actors in making EES related to building refurbishment or to electricity saving measures in low-income households financially viable.

In Denmark, Flanders and France energy companies address basically the same technologies and fields of application as in Germany, although in these countries and regions there is an energy saving obligation in place for energy companies which mainly stimulates these companies to supply EES to their customers. The white certificate scheme in place in France has seemed so far particularly effective in fostering the supply of EES related to the installation of individual and collective condensing boilers, high energy performance boilers, heat pumps and insulations measures. In Denmark most of the EES relate to the installation of efficient boilers and efficient ventilation and heating systems in general [5], whereas in Flanders the most common actions include super-insulated glazing, condensing and high-efficiency boilers, roof insulation in existing buildings [6].

In the four countries mentioned above, and in general, the target group of single households is however often reached by energy companies only through partial services connected to EES, like information, energy audits, etc., aiming to increase customer loyalty.

Clearly also actors different from ESCOs and energy companies are typically active in the EES market, especially in countries with a long tradition of public subsidies in the housing sector (e.g. Austria). Social housing corporations, project developers, architects, investors, building companies and installers of energy using systems in the construction sector are other important EES market actors. Moreover energy consultants, auditors and engineers play an important role in the EES market, especially in those countries where this market relies on regulations related to building energy certification and/or energy audits.

However, whereas some of these company types may offer integrated services and cover the whole EES value chain, most of them may decide to focus on specific value chain stages. The cross-country analysis performed in the framework of the ChangeBest project shows that ESCOs rarely concentrate on information and awareness raising on EES in the countries where they operate. Additionally, their activity related to EES financing is often just limited to the identification of third parties available to finance EES investments (i.e. they typically do not finance EES investments with internal funds). Moreover, the provision of energy saving measurement and verification by ESCOs and energy companies is often a consequence of the stipulation of EPCs or the need to achieve some mandatory and measurable energy saving target (e.g. in Denmark, France, Flanders, Italy).

Information and awareness raising activities may be performed by energy agencies (like e.g. in Portugal) which could be interesting partners for EES providers, both in the stage of information and awareness-raising, and in the saving measurement and verification stage, by introducing more credibility and transparency in the EES provided. In some countries (e.g. Austria) banks are active on information and advice on EES which represent part of their marketing activity related to the credit lines they offer for EES. The provision of energy supply in combination with EES by energy companies seems to be a common practice in countries where a well developed EES market exists (e.g. in Denmark, Germany, Flanders), whereas in the countries where the EES market is still in a preliminary development stage (e.g. Slovakia, Poland) this service combination is rare or not provided at all.

The analysis performed also considered technologies and fields of application for EES offered to the various possible customer groups in the countries covered. This survey addressed the main sector cross-cutting technologies and fields of applications in the sectors of industry, residential, commercial, public/service and agriculture.
Table 2 below summarises the results of the survey performed for those cross-cutting technologies and fields of applications constituting the EES market which may relate to the residential sector. This

[5] However, such EES have become more difficult in recent years due to a legal decision that house owners are not allowed to transfer payment of the EES contract to the tenant. Existing political proposals to overcome this barrier by changes in tenant law have not been implemented yet.

table shows that energy efficiency improvement measures addressing building envelope insulation and heating systems are the sector cross-cutting technologies and fields of application mostly indicated in the country reports as typically addressed for the provision of EES[6].

Table 2 : Main sector cross-cutting technologies and fields of application for the EES provided in the countries analysed ("XXX" = *much more frequently preferred*, "XX" = *more frequently preferred,* "X" = *less frequently preferred technologies*)[7]

	Cross cutting technologies							
Country	**Building envelope insulation**	**heating system (incl. DH), hot water system**	**air conditioning**	**Ventilation**	**water saving**	**building automation and control systems**	**user behaviour training**	**Pumps**
DE	xx	xx	xx	xx				x
DK	x	xxx	xx	xx				x
BE	x	x					x	
SE	x	xx		xx	x	xx	xx	
NL	x					x		xx
AT	xx	xx					xx	
FR	xx	xxx	x	x		x	x	xx
IT	x	xx	xx		x	x		
CZ	xx	xx						
PT		xx	x	x				
ES		x	x	x		x	x	
LV	x	xx				x		
SK	x	x						
SL	x	x				x	x	
EE	x	x	x	x				
BG	x	x					x	x
EL	x	x	x					
PL	xx	xx	x	x		xx	x	

Concerning EES financing and contracting, successful pure business models addressing EES supply in the residential sector are very rare in the countries analysed. Probably for this reason EES financing and contract types adopted in these countries are also not very evolved. Whereas a good level of market activity has been identified (e.g. in Germany, Denmark, Flanders, France) this activity is typically supported by energy efficiency policy measures like energy saving obligation, tax deduction, tax credit schemes or subsidies. It is often quite unlikely that this activity could continue to exist on a pure commercial basis without any form of economic support provided through these policy measures.

[6] Notice however that the information related to the different preference degrees for the various technologies and field of applications registered in the various countries refers to all possible sectors and could hence not actually indicate the actual variation in the preferences existing in the residential sector

[7] The three different preference degrees possibly reported in this table serve to highlight the possible differences *in a same country* and do *not* reflect the different preference degree for a given technology or field of application in *different* countries.

As already mentioned energy companies decide in some case to provide these services for commercial reasons in order to increase customers‘ loyalty or to acquire competitive advantage over existing competitors. Third Party Financing (TPF) is typically more common for the largest investments (e.g. in case of EES implemented by housing associations or real estate companies) or in those countries where banks have developed sufficient expertise and confidence in the EES business (e.g. Austria).

EES are often provided in combination with energy supply or contracts for operation and maintenance of energy systems at the energy end-users sites. Contract types stipulated in the EES business in several countries analysed are leasing, Build-Own-Operate-Transfer (BOOT) contracts[8], chauffage[9]. Energy performance contracts (EPCs) are very rare. Some examples of EPCs stipulated in the residential sector have been identified in Sweden [7], Flanders [8], Latvia [9].

Existing energy efficiency policies affecting EES market development in the residential sector

As already mentioned, a specific analysis structure that describes in general how policy measures can influence the demand for and the supply of EES has been developed in the framework of ChangeBest [2] and has been used to analyse the policy measures of countries. Policy measures affecting the EES market have been categorised as:

(1) specifically targeting EES providers,
(2) creating or supporting general mechanisms for an EES-market,
(3) stimulating one or more EES activities,
(4) stimulating energy savings and thereby EES activities indirectly,
(5) restricting the (commercial) market for EES.

Concerning policy measures specifically targeting EES providers, a distinction can be made among (a) measures for accreditation/certification of ESCOs or offered EES, (b) measures for the creation of platforms for ESCOs with common interests, (c) measures providing specific support for ESCOs (e.g. financial) and (d) legal arrangements often regarding the removal of barriers for ESCOs.
Clearly the potential for EES market development in a country cannot be directly correlated to the number of measures targeting EES providers in place. However, the overview performed highlighted that only a few countries have no measures specifically devoted to directly improve EES providers position (i.e. Bulgaria, Latvia, the Netherlands), whereas few countries have implemented more than two of the above mentioned policy measure types (i.e. Italy, Poland, Spain). Support is given in various ways, sometimes by extra subsidies for ESCO projects, a few times as preferred partner (Czech Republic) in energy saving projects. Financing of investments by ESCOs is generally part of policy on TPF, which however is not always related to projects implemented by ESCOs. This support can be positive but in principle can restrict the activities of other commercial EES providers and it can be debated whether this actually stimulates a commercial EES market.

Concerning policies creating a general mechanism for EES, like WCS (white certificate schemes), EPC (energy performance contracting), TPF (third party financing) or comparable schemes, these measures can in principle create ample opportunities for EES providers. Policy measures stimulating EPC and TPF are mentioned for 7-8 countries, although EPC are rarely adopted in the residential sector.
The above mentioned mechanisms create opportunities but they do not lead by definition to a thriving EES market because of the market barriers existing especially in the residential sector or the absence of a level playing field for EES providers. For example WCS can bring additional cash flow for EES providers and shorten payback times for the actors involved in EES implementation. Moreover WCS

[8] These contracts (Build-Own-Operate-Transfer) may involve an EES provider designing, building, financing, owning, and operating the EE equipment for a defined period of time and then transferring its ownership to the client. These are long-term supply contracts where the service charges include capital and operating costs recovery as well as project profit.
[9] The EES provider takes over complete responsibility for the provision of an agreed set of energy services. This arrangement is an extreme form of energy management outsourcing. Where the EES market is competitive, the EES provider also takes over responsibility for fuel/electricity purchasing. The fee paid by the client is calculated on the basis of its existing energy bill minus a percentage saving so that the client is guaranteed immediate savings. The more efficient is the EES provider, the greater its earnings. If well designed chauffage contracts give strong incentives to EES providers to supply effective and efficient services.

create an institutional and independent back-up to EES (energy savings are certified by a public authority) and can create harmonised and recognised procedures for measurement and verification of energy savings. Nevertheless, EES providers different from energy companies are not always eligible to get and trade certificates under the existing schemes. Furthermore, EEI actions so far mostly implemented could hardly be part of a self-sustaining long term EES market because they typically are the easiest and cheapest to implement (e.g. they relate to CFLs or low flow showerheads installation)[10].

Concerning policy measures that stimulate one or more EES activities in the value chain (such as raising awareness, providing information, advice on saving measures, technical planning and monitoring of results) many types of EES activities are stimulated by such policy measures in place in the countries analysed. However, there are only single policy measures in place, and hence, there is a need for a complete set of policy measures ('policy packages') that stimulates *all* EES activities that are necessary in order to realise energy savings.

Concerning policy measures stimulating energy savings and thereby EES activities indirectly, all countries surveyed deploy policy measures to stimulate savings of the following types: energy performance standards for new dwellings/buildings, minimum efficiency standards for appliances, labelling of buildings and appliances, subsidies or favourable loans or tax-deductions, voluntary agreements, taxes on energy or on CO2 emissions and emission trading scheme. Whether these policy measures stimulate the demand for EES depends on the complexity of solutions. Stimulation of simple solutions, such as efficient refrigerators, does not lead to more demand for various EES activities. Stimulation of complex solutions, such as renovation of buildings or installation of CHP, does provide opportunities for EES providers. Further on, some stimulating policy only creates a temporary market for EES, such as for very efficient new dwellings that will become common building practice in time.

Finally, concerning policies restricting the EES market a distinction can be made between legislation that restricts EES companies in their operation and policy measures that restrict the commercial market for EES. Legislations restricting EES providers activity relates for example to the prohibition of external funding of energy equipment in "chauffage contracts" in France, the requirement that all tenants of multifamily buildings must agree on investments by ESCOs (e.g. in Germany and Slovenia), the low and regulated heat prices not leaving room for ESCOs investments in Poland, the restricted transfer of district heat costs to the consumers in the Netherlands. Most of the legislative problems are not related to energy savings but regard arrangements between parties in general. In a number of countries policy measures have been formulated to lift the legislative barriers, as demanded in the ESD. However, the observed problems show that in many countries this demand has not yet been met. Policy measures stimulating public supply of EES which competes with commercial offers can actually restrict the commercial EES market. Examples are free energy checks/advice by energy agencies, government supported/erected ESCO's, support for training of energy experts and attractive subsidies only for energy users. Whether the public offering of EES restricts the commercial EES market or not also depends on the targeted end-users[11], the type of EES activity (awareness raising is generally a public EES activity), the terms for public EES offering and the EES market development status in the residential sector. In particular public offering of, or public economic support for EES in the residential sector can in principle serve to stimulate the commercial market for EES whereas this market is in an initial development stage, this being case in practically all the countries analysed.

Also EU policy (ESD, EPBD, CHP, Ecodesign Directive, Labelling and ETS) transposed into national policy measures can be dealt with in the analysis of national policy measures. EU policy affecting European actors hardly influences the EES market. Although EU policy, as highlighted in the ESD, has a large indirect effect on the EES market, the direct effect of EU policy measures is very limited.
In general all the policy measures above described can be categorised as mostly indirectly, but partly also directly positively or negatively influencing the EES market via the supply side or via the demand for EES. Most policy measures directly targeting EES providers or EES activities are supply-oriented, e.g. policy measures that increase the quality of offered EES. Overall, far more policy measures

---

[10] However the situation might change in the next years because more costly EEI actions could be implemented by obliged actors to achieve their saving targets because the so called "low hanging fruits" will have been harvested and because the new saving targets will generally be much higher than in the past.

[11] For example public EES offering may be necessary for single dwellings, which are typically very difficult to achieve by EES providers, whereas this offer might in principle restrict the commercial EES market for multifamily buildings.

influence the EES market via the demand side, and mostly only indirectly. However, influence via the supply side could be more focused and therefore more effective than indirect influence through the demand side.

Existing EES market potentials in the residential sector

The potential market volume which can be generated by future promising EES in the residential sector has been estimated in the framework of ChangeBest [3]. This estimate has been mainly derived from assessments of the economic and technical energy saving potentials in 2020 as available in [10]. The market volume available for future activities in the field of EES has been indeed derived by pricing these potentials with the corresponding final end-users' energy tariffs[12], as reported in the EUROSTAT database. Energy saving potentials considered in the ChangeBest analysis refer only and exclusively to EEI actions related to *space and water heating in existing residential buildings*.

Following the approach adopted in [10] estimates have been first performed by indicating a range of variability for the potential economic energy savings which have been assessed by considering a baseline scenario, a low policy intensity scenario (LPI) and a high policy intensity scenario (HPI). Whereas the baseline scenario extrapolates past autonomous energy efficiency improvement rates, including the impact of early energy savings (adopted through 2006), the LPI scenario assumes high barriers to energy efficiency, an increase in the policy effort to overcome these barriers compared to current policies and considers the implementation of EEI actions which are cost-effective for the whole country. The HPI scenario assumes a removal of the barriers to energy efficiency achieved by a high policy effort and considers actions whose implementation is cost-effective for the consumer[13] (see [10] for further information and details). The overall economic energy saving potentials in EU-27 by 2020 have resulted of 140 TWh final energy under the LPI scenario and of 379 TWh final energy under the HPI scenario, of which are 125 TWh fuel savings and 15 TWh electricity savings in the LPI scenario and 358 TWh fuel savings and 21 TWh electricity savings in the HPI scenario. The annual economic energy saving potentials (estimated for each EEI action considered in each of the EU-27 countries) have been multiplied by the corresponding country specific end-users' energy tariffs and have resulted in an annual additional EU-27 potential market volume of 527 M€ under the LPI scenario and of 1438 M€ under the HPI scenario.

The huge difference registered between electricity and fuels potential additional savings comes mainly from the fact that future electricity savings deriving from the installation of most of the energy efficient domestic electrical appliances are not considered (because these EEI actions could very hardly be part of EES), the fact that the energy performances of installed electric heating systems are assumed as hardly improvable, the fact that heat pumps, which are responsible for a significant amount of the estimated energy savings, are assumed to be mostly installed in substitution of existing oil or gas fuelled heating systems. The big variation between the economic energy saving potential estimated under the LPI and HPI scenarios derives instead mainly from the marked improvement of building envelopes energy performances assumed under the HPI with respect to the LPI scenario.

Although it could be roughly assumed that the actual EU-27 economic energy saving potential that will be exploited by 2020 through the implementation of EES lies somewhere between the potentials estimated respectively under the LPI and HPI scenarios, it should be also considered that these potentials include the possible implementation of EEI actions with a long investment payback time that could be hardly considered for the stipulation of EES contracts. For this reason the energy saving potential that might be in principle exploited by EES has been also estimated by adopting the following approach as an alternative to the one just described above: instead of assuming that this potential is made by those additional EEI actions which would be implemented under the LPI or the HPI scenarios, it has been assumed that this potential is made by those additional EEI actions having reasonably short payback times that could be implemented according to what foreseen by the technical scenario (TECH) considered in [10][14]. The technical energy saving potential due to EEI

[12] All energy prices considered are prices before taxation and are expressed in 2007 € values

[13] Cost-effectiveness has been calculated in [10] from the sum of annualised investment costs, annual operation and maintenance costs minus the annual financial savings from lower energy bills. Capital costs have been annualised over the technical lifetime of the actions with a discount rate of 8% under the LPI scenario, and a discount rate of 4% under the HPI scenario. Energy prices are energy price after taxation and are expressed in 2005 € values.

[14] This scenario implements EEI actions to a level that is assumed to be technically achievable and takes into account also measures that are not cost-effective and whose related investment payback time is hence longer than measures' lifetime, although it does not include extremely costly measures (see [10] for more information).

actions related to space and water heating systems in the existing residential buildings of the countries of the EU-27 has been then analysed with respect to the payback times[15] of these actions (which may be, and actually are, different in each of these countries) [3].

Figure 1 reports the cumulated technical energy saving potentials estimated for the various EEI actions considered in each of the EU-27 countries vs. the average payback times of the related investments as estimated for each of these countries. These national technical potentials have been sorted by rising payback time and cumulated in order to represent the EU-27 "offer curve" of technical energy savings.

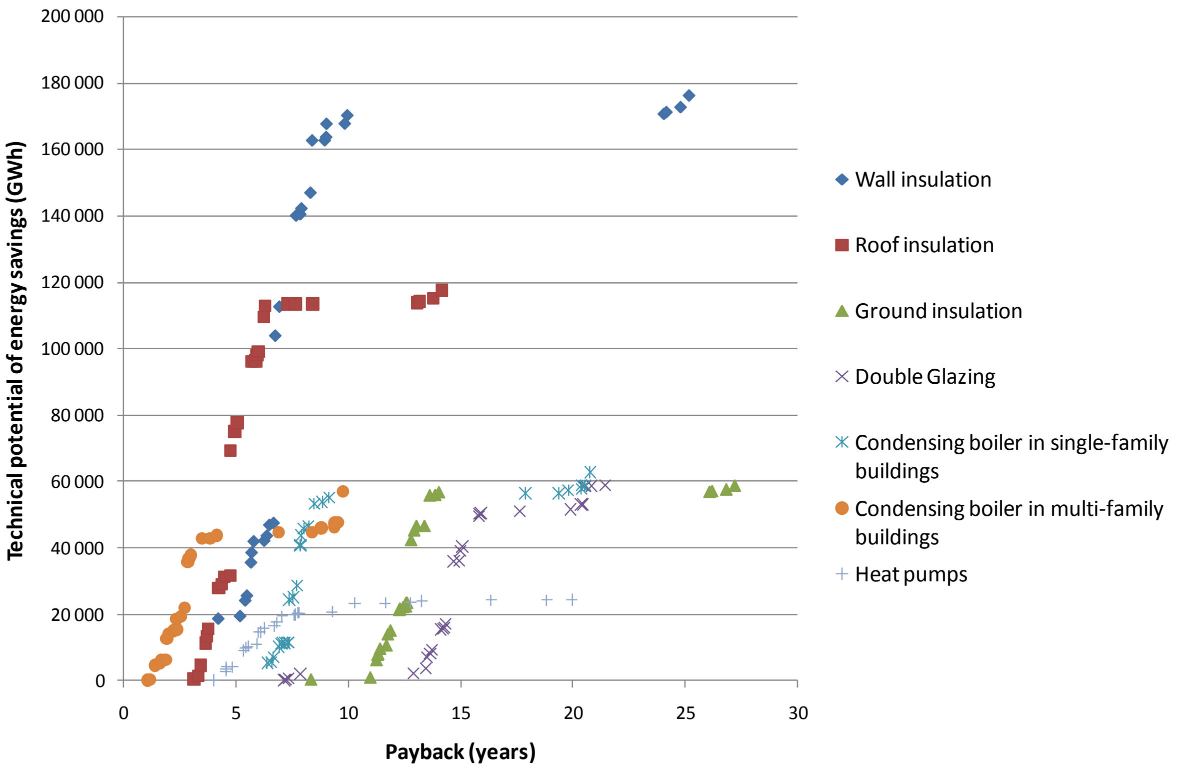


Figure 1: cumulated technical energy saving potential estimated for the various EEI actions considered in each of the EU-27 countries vs. payback times of the related investments as estimated for each of these countries [3].

Figure 1 indicates that the largest potential could come from wall and roof insulation. Both EEI actions can be implemented with short investment payback times in the countries with moderate or warm climates. This potential is less exploitable in colder climates because of the better quality of existing insulation solutions.

Boiler replacement has on average a short payback time and represents hence a very open EES market potential, mostly in multi-family buildings for which payback times are very short (less than 5 years for most of the countries). Heat pumps have also short payback times but their energy saving potential is smaller.

Finally, double glazing[16] and ground insulation represent a non negligible potential but their payback times seem to be too long to be considered as a potential open to EES (more than ten years).

The overall technical energy saving potential of the EEI actions considered for the residential sector and represented in Figure 1 corresponds to around 555 TWh in 2020 whatever the payback time. If we translate these figures in terms of yearly market, the yearly potential additional market volume open to EES results around 2 440 M€. But that would imply that investment payback times of some EEI actions would be longer than 25 years and EES contracts stipulated for their implementation would probably have to last at least for as much time, which seems fairly unrealistic. If we order these

[15] Payback times are estimated by assuming a zero discount rate

[16] Thermal performances of windows frames have not been taken into account and estimated energy savings derive hence only from glazing improvement.

technical potentials by their corresponding payback times it results that the yearly additional potential market open to EES could reach 194 M€ if the investment payback times (and hence the corresponding EES contract durations) were limited to 3 years. This analysis has also shown how a much higher potential could be exploited if EES could be offered on a longer period thanks to suitable policy measures or by providing new types of EES (in particularly long-term contracting types). With less than 8 years contracting, the annual additional EES potential market open to EES rises indeed to 1 644 M€, whereas a less accessible market potential of 795 M€ is made of investments with payback times over 8 years (see table 3 below).

Table 3: Potential of the market open to EES for the residential sector in EU-27 – Summary [3]

Additional market for EES according to their accessibility (yearly market in M€ up to 2020)		
Very accessible (PBT < 3 years)	Accessible (3 years <PBT< 8 years)	Less accessible (PBT> 8 years)
194	1 450	795

Conclusions and recommendations on the formulation of policy measures

The country analyses performed in the framework of the ChangeBest project indicate that the development status of the EES markets in the residential sector is typically ranked at lowest level with respect to EES markets in other demand segments. Despite the estimated existing potential for an additional annual market volume in the EU-27 of about 190 M€ and made of investments with payback times below 3 years (or of about 1640 M€ made of investments with payback times below 8 years), experts are sceptical about a possible significant EES market development in the near future because of the specific barriers existing in this sector (notably the high transaction costs relative to the amount of energy costs, the high fragmentation of this mass market, the existing situations of split incentives, the rules regulating the decision processes in many multi-apartment buildings, the lack of standardised procedures for measurement and verification of energy savings).

Nevertheless the analysis of existing policy measures affecting this market segment has highlighted some main directions of improvement for stimulating its development. This has allowed the ChangeBest project consortium to produce a series of preliminary recommendations for policy makers that may be briefly summarised as follows.

Given the significant heterogeneity of national situations, it is obviously not possible to recommend a common EU policy approach to kick-start a market for EES in the residential sector. However an important support could be provided at the EU level in helping to overcome existing financing barriers by specifically addressing banks and/or by arranging guarantee funds for EES (e.g. through the EIB). In addition in most EU Member States (MS) there is need for a more effective integrated and centrally co-ordinated approach to EES implementation because of the presence of the many intermediate actors typically involved (e.g. agencies, housing corporations, installers and manufacturers of efficient systems, etc.)[17] and there is need for a common understanding of what should be meant by EES, EPC, etc. when designing EU[18] and MS policies (see for example the EN 15900).

At the MS level, national policies hindering the implementation of EES (e.g. the tenant law in Germany) or being a barrier towards the development of a level playing field (e.g. policies and support programmes that do not allow energy companies to offer specific EES) should be revised or removed. Moreover a mechanism allowing financing energy efficiency improvement actions and offering EES in the domestic sector should probably be implemented in every MS (e.g. an energy efficiency fund and/or an energy saving obligation scheme like the ones presently implemented in some countries for energy suppliers or distributors), although it would be also important to envisage how to shift from the provision of EES due to an obligation or support scheme to an independent and profitable EES market when suitable market conditions are created.

[17] It may be interesting to notice that whereas a problem of split incentives for building renters and owners arises, EES providers could act as a broker and allow meeting the interests of all parties while realising the saving measures.

[18] In particular EU policy, but also national policies, can increase trust into EES and EES providers by supporting information, qualification, certification and accreditation and training programmes, particularly in promoting and supporting harmonisation of such programmes between Member States, e.g., in terms of requirements and quality, and by supporting respective platforms and networks for exchange of experiences, standardised EES contracts and measurement and verification procedures.

Unwanted competition to the commercial provision of EES at the national level should also be avoided. For example it should be considered to replace possible free audit schemes of energy agencies by subsidies of energy audits valid for all EES providers.

In general policy packages stimulating both demand and supply of EES simultaneously would be highly beneficial especially because policies stimulating supply of EES are rare at the moment. Finally financial subsidies for soft loans or guarantee schemes to boost the EES market could be implemented by MSs (e.g. national governments or local administrations could collaborate with banks to offer EES at low interest rates, to offer financial guarantees that reduce investment decision risks, to create revolving funds to finance projects carried out by EES providers).

Overall the provision of financial subsidies and/or incentives for EES should always be considered as temporary policy measures to be implemented only during EES market initial development stages, whereas policy measures facilitating the creation of competitive EES business models should always have the priority, although the creation of these models seems to be particularly difficult for EES supplied in the residential sector.

References

[1] Labanca, N., *Status and development of the energy efficiency service business in 18 EU countries*, 2010. Can be downloaded at www.changebest.eu

[2] Boonekamp, P., Vethman, P., *Analysis of policy mix and development of the Energy Efficiency Services, produced in the framework of the ChangeBest project*; April 2010. Can be downloaded at www.changebest.eu

[3] Duplessis, B., *Analysis of the potential market volume for energy services*, 2011. Can be downloaded at www.changebest.eu

[4] CEN (2010): *European standard EN 15900:2010 on Energy Efficiency Services*

[5] Ea Energianalyse, Niras, RUC og 4-Fact (2008): *A way to higher energy efficiency. Evaluation of all Danish energy efficiency activities*

[6] Bertoldi, P., Rezessy, S., Eoin, L., Baudry, P., Jeandel, A., Labanca, N., *Energy supplier obligations and white certificate schemes: comparative analysis of experiences in the European Union*, Energy Policy 38 (2010) 1455–1469

[7] Lindgren K. (2009). *Transforming the Efficiency Gap into a Viable Business Opportunity: An Evaluation of the Swedish ESCO Experience*. Master Thesis at Department of Technology and Society, Environmental and Energy Systems Studies LTH, Lund University.

[8] Coolen, J., *Report on the EES business in the Flemish region of Belgium produced in the framework of the WP2.1 of the ChangeBest project*; 2010. Can be downloaded at www.changebest.eu

[9] Rochas, C., Blumberga, D., *Report on the EES business in Latvia produced in the framework of the WP2.1 of the ChangeBest project*; 2010. Can be downloaded at www.changebest.eu

[10] Fraunhofer-Institute et al., *Study on the Energy Savings Potential in EU Member States, Candidate Countries and EEA Countries*, Final Report for the European Commission DG-TREN, EC Service Contract N° TREN/D1/239-2006/S07.66640, 2008

Acknowledgements

The authors of this paper would like to thank and are extremely grateful to all the colleagues and partners who are contributing to the ChangeBest project. For a full list of partners and for further information on the ChangeBest project and papers published so far, please visit the project website: www.changebest.eu. The project has started in July 2009 and will run until June 2012.

Review of China's new policy framework to boost the market for ESCOs

Li Pengcheng, Liang Xiuying, Chen Haihong

China National Institute of Standardization

Abstract:

The concept of energy services companies (ESCOs) was introduced in China in the middle of 1990s by the World Bank. Three pilot companies were also established at the same time in Beijing, Liaoning province and Shandong province. In 2009, the annual total output value of ESCOs in China almost reached $ 8 billion. Recently, it is recognized that there are several serious obstacles blocking the development of ESCOs in China, especially related to financing incentives, taxes system, accounting system, loan and credit as well as technical capacity like measurement and verification standards.

In April 2010, China government published a milestone document to boost the market for ESCOs. An ambitious target was brought out that in 2015 the EPC projects will be the most popular way chosen by energy-using facilities to improve their energy efficiency. Then it is also expected that improvement of energy efficiency in China will be mainly driven by the market mechanism but not by government or regulations. Therefore, a new policy framework was proposed to promote the ESCO in a formal government document. It looks like that these series of policies may overcome the above obstacles very well. This paper will review the advancement of this policy framework in China and conclude what is the key factor which influences the penetration of ESCOs. It is also pointed out in the paper that some key factors to support the prosperous ESCOs were not sufficiently considered in this policy framework. This may weaken the impact of the policies largely in the future.

1. Introduction

ESCO concept emerged in Europe more than 100 years ago. But it is well known from the successful experiences in US. Sorrell gave a thorough insight in the economics of EPC.[1] The market of energy efficiency services in Western Europe was estimated to be 5-10 billion Euros annually.[2] Throughout the U.S. energy services company (ESCO) industry's history, public/institutional markets continue to host the majority of ESCO industry activity. ESCOs have invested about 15-19 billion dollars in projects at U.S. public/institutional facilities since the early 1990s.[3] Nowadays, the concept of ESCO is accepted widely in the world. Many developed and developing economies present plenty of experiences in the promotion of ESCO market.[4][5][6]

The unbalance between China's restrictive energy supply and its soaring energy demand is known as an obvious necklace for the sustainable development of economy. In 2006, China pledged to reduce energy consumption per GDP by 20% in the period of 11^{th} national five-year guideline for the economic and social development (from 2006 to 2010). In the January of 2011, China stated that total energy consumption per GDP in 2010 has decreased 19.1% than in 2006. In 2009, China has also made a promise to reduce the intensity of greenhouse gases emission per GDP by 40% to 45% before 2020.

Till now, most actions to improve energy efficiency or reduce emissions were taken in a top-down way in China. Namely, China central government sets the directives or requirement for key energy-consuming organizations or local governments and also inspects or supervises the achievements of energy savings. For example, in the period of 11^{th} five-year plan, the target to improve energy efficiency was reached mainly by two top-down lines: one is "central government-provincial government-local government-energy consuming entities (most are industrial enterprises)", the other is "central government-top energy consuming industrial enterprises" (about 1,000 enterprises with a threshold of annual energy consumption of 180,000 tce).

China central government paid attention to the energy services companies (ESCOs) for a long time. Administrations called it a new mechanism for energy conservation to distinguish it from the traditional top-down methods. ESCOs are considered as an alternative tool driven by market mechanisms to realize the energy conservation. The main reason for the highlight of ESCOs is that central government found the cost of improving energy efficiency is too high by a top-down way. It is a common idea that the industry regards the improvement of energy efficiency as a heavy burden and often has negative attitude. The government hopes the introduction of market mechanism in improving energy efficiency can be successful as in the economic development.

2. Development of ESCOs in China

In 1998, the World Bank (WB) and Global Environment Facility (GEF) carried out a well-known program to start the energy efficiency services market in China. In the first phase of the program, 3 pilot ESCOs were established in Liaoning, Shandong and Beijing. Part of the capital of these pilot ESCOs were loaned by WB. During the second phase of the program since 2003, EMCA (Energy Management Company Association) was established. This non-government body is expected to play the role of a sector association to provide policy suggestions, information exchange, and capacity building etc. Furthermore, a guarantee fund for ESCOs' loan in operating EPC projects was operated by the state-run China Investment and Guarantee Company (I&G). The fund was invested by WB partly. From 2010, the program moved forward to its third phase, 3 banks were chosen to demonstrate the financing model for ESCOs. WB loans 3 banks to leverage their larger financing on the ESCOs' projects.

Promotion of ESCOs is frequently mentioned in the legislation and the official documents relating to energy conservation. It is mentioned in the law of energy conservation that government encourages the promotion of ESCOs. In the national plan to cope with the climate change published in 2009, ESCOs were indicated as an innovative mechanism for coping with climate change and energy conservation.

The number of ESCOs in China has remarkably increased since 1998, from 3 to almost 800 in 2010. Especially from 2006 to 2010, investment in EPC projects has increased significantly thanks to the stimulation represented by the previously mentioned national energy conservation objective of 20%.[7] Fig. 1 shows the trends of investments on EPC projects. Since most ESCOs here are small-and-medium-sized enterprises (SMEs), it shows a big advantage on creating jobs. By the end of 2010, the number of employees in ESCOs exceeds 170,000, ten times the ESCO employee number of 2006. The total energy savings of EPC projects during 2006 to 2010 is estimated to be 22.4 million tce. It also means GHG reduction of 61 million ton annually.

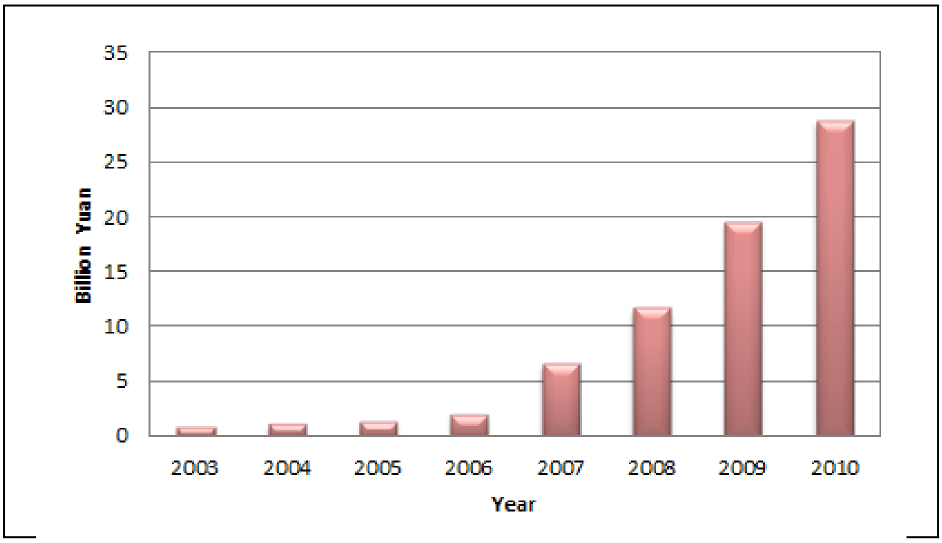


Figure 1. Investment on EPC projects in China

Source: Development report of China ESCO industry in 11^{th} five-year plan (EMCA, 2011, in Chinese), 1 US dollar is approximately equal to 6.5 Yuan.

China's market of energy efficiency services has some features which are different from US or EU market. The first is that most projects are conducted in industry projects. The share of investment on EPC projects in different sectors is shown in Fig. 2. It can be found that investment on industry projects keeps a high share of about 70% in 2009. It keeps consistent with the total energy consumption of related sectors.[1] It should be noticed that industry projects have high instability depending on operation process and economy situation. Secondly, top ESCOs of China mostly are manufacturers of efficient products or energy saving products (like variable speed drives, VSD). EPC project is typically implemented to reduce the pressure on buyers' cash flow. Consequently, the biggest share (57%) of EPC type in China is the type of guaranteed savings since the type of shared savings has longer duration and more cost for measurement and verification. Finally, most EPC projects have a very short payback time (2 or 3 years). Since integrity of owners is not very assured, most ESCOs like to implement the short time projects to reduce the risks.

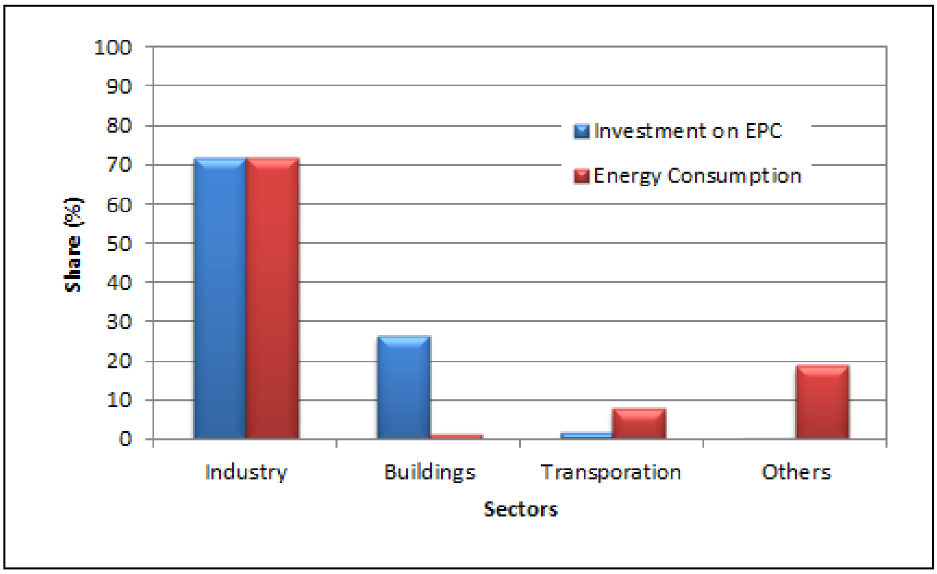


Figure 2. Shares of Investment on EPC projects and energy consumption in different sectors in 2009

Source: Energy consumption data is from Chinese Statistics Yearbook (Statistics Press, 2009), Investment data is from Development report of China ESCO industry in 11th five-year plan (EMCA, 2011, in Chinese)

3. The new policy framework for ESCOs in China

In April 2010, it is a milestone that China central government published a formal document to bring forward an ambitious objective for the development of ESCOs. This document was drafted by National Development and Reform Commission (NDRC), Ministry of Finance (MOF), People's Bank of China (PBC) and State Administration of Taxation (SAT). Based on the analysis of key barriers in the market, a series of policies were suggested to boost the market for ESCOs (see table 1).[8]

Table 1. Policies proposed and ESCO market barriers addressed

[1] The classification of building in China is a bit different from US or EU. EPC projects in building is popular in business building or public building in China.

Main market barrier addressed	Policy measures implemented
Difficulties in financing	● Financial institutes shall provide services on financing and factoring ● Assets in EPC project is accepted to apply for mortgage lending from banks
Imperfect taxation for ESCOs	● Temporary exemption from sales tax of ESCOs (the end of the date is not mentioned in the documents) ● Exemption from VAT (the beneficiary (ESCO or owner) is not mentioned in the documents) ● Once it has gotten the first sum of income through EPC projects, ESCOs can receive exemption from income tax in the first 3 years and half rebate of income tax in the next 3 years. ● Project expenditures of owners can be deducted from the taxed income without any caps ● Accelerated depreciation for assets in projects
Lack of incentive policies	● Subsidy from public finance on the energy savings of EPC projects ● Public institutes should implement EPC projects when retrofitting
Incomplete accounting system	● Payment of public institutes to ESCOs could be treated as the energy bill ● Conditional payment of enterprises to ESCOs could be treated as expenses ● Handover of the assets could be treated as bestowal

Source: Opinion for promotion of energy performance contracting and development of energy efficiency services (document by NDRC, MOF, PBC and SAT, in Chinese)

As a highlight of the policies framework, the subsidy program was kicked off by NDRC and MOF in June 2010.[9] At least 300 Yuan (about 46 dollars) per tce of energy saved can be subsidized to the registered EPC project according to its annual energy savings. The annual energy savings of the subsidized project should be less than 10,000 tce and more than 100 tce (an industrial project should be bigger than 500 tce).[2] The type of subsidized EPC projects is restricted to shared savings contracting. The ESCOs ready to receive the subsidy should be included in a registration list released by the government. Listed ESCOs need submit the application and pass the inspection by governments for energy saved actually before they received the subsidy. The subsidy is provided by central government and local government together: a fixed share of 240 Yuan per tce by central government and a flexible share with at

[2] China has already implemented a subsidy program for the owners of retrofitting projects with annual energy savings more than 10,000 tce from 2006.

least 60 Yuan per tce by local government are subsidized. Local governments were stimulated to give more subsidies to achieving more energy savings since its high pressure on improving energy efficiency. Beijing, the capital city of China has promised to provide 260 Yuan per tce of energy saved which exceed the share of central government. The amount of total subsidy from central government in 2010 has been estimated around 2 billion Yuan.

Some supporting activities were also encouraged in the document, including: a) improve the capacity of ESCOs; b) development of sector association; c) establishment of suitable environment for ESCOs by dissemination activities, pilot projects implementation, information exchange stimulation and so on.

4. Review of the policy framework

Market of ESCOs has been stimulated by the policies framework significantly. At the end of 2010, the number of the ESCOs almost increased by 50% with respect to 2009. By the document, it is expected that, in 2015, the market of ESCOs will be further developed and EPC projects will be the main model of the project for energy saving retrofitting. According to the report of EMCA, the number of ESCOs may exceed 2,500 in 2015 and investments on EPC projects could reach 150 billion Yuan. This would also mean achieving annual energy savings of 40 million tce.[7]

The systemic policies framework implemented is very impressive. Especially a series of polices designed based on market barriers analysis provide a good model in the development of China's energy efficiency policies. Besides, taxes rebates, adjustment of accounting system and subsidy program cope with the essential problems for most ESCOs. It is hence believed the policies framework will impact the market largely.

However, it should be noticed that some key issues were not covered by the policies framework. This may weaken the effect of these policies:

1. Small-and-medium-sized ESCOs do not receive special treatment in the policy framework. In fact, these ESCOs occupying a big share in the market have more difficulties to be financed and supported;

2. There is still lack of tools to improve integrity of the market. Most ESCOs in China have experienced the payment defaults. In some cases, this is fatal for the cash flow of ESCOs.

3. There is a big gap to be filled without mandatory requirements on public institutes to implement EPC projects. It is evident that the successful demonstration of EPC projects in public institutes is very persuasive to promote the market of ESCOs.

Normally, there are higher integrity and longer duration for EPC projects in public institutes[3];

4. The cost of the subsidy program is still very high for both the government and ESCOs. ESCOs need to do a lot of work for applying the subsidy and to pass the inspection by local governments. The cost for local governments to operate the administrative system and verify the actual energy savings of EPC projects is very large. It is anticipated that a market-based 3rd party certification system for energy savings will be more cost-effective;

5. The technical consensus of energy savings among stakeholders is not very concrete. The standards, specifications or protocols for measurement and verification of energy savings are missing. Considering that accredited energy savings are the central point of EPC projects, a solid technical agreement how to determine energy savings is very important. Unfortunately there are no standards or protocols for the determination of energy savings in the industry till now. Although energy metering has been mentioned in the document, standardized methods to determine energy savings are missing.

5. Conclusion

ESCOs have a short history in China as they were introduced from foreign countries in 1998. Nowadays, the important role of ESCOs is widely recognized by administrations and sectors. Since around 70 percents of total energy is consumed by industry in China, we can find most EPC projects here are carried out in industrial enterprises.

The government document published in April 2010 is a milestone for China's market of ESCOs. This document provides a systemic package of incentive policies. The policy framework was brought forward on the basis of key market barriers of ESCOs. It is expected to stimulate the market in a very short time as it provides very attractive circumstance for ESCOs.

Nevertheless, five key issues did not receive sufficient attention: the special interests of small-and-medium-sized ESCOs, the low integrity of market, the missing demonstration of public institutes, the low cost-effective operation of subsidy program and weak technical consensus on energy savings claimed. This may cause this remarkable policy framework will not be as successful as expected.

References

[1] Steve Sorrell. *The economics of energy service contracts*, Energy Policy, Vol. 35 2007, pp. 507-521.

[2] Paolo Bertoldi, Silvia Rezessy, Edward Vine. *Energy service companies in European countries: Current status and a strategy to foster their development,* Energy Policy, Vol. 34 2006, pp. 1818-1832.

[3] Nicole Hopper, Dave Birr, Kate McMordie Stoughton. Public and institutional markets for ESCO services: comparing programs, practices and performance, March 2005. Can be downloaded from www.lbl.gov.

[4] Edward Vine. *An international survey of the energy service company (ESCO) industry*, Energy Policy, Vol. 33 2005, pp. 691-704.

[5] Esin Okay, Nesrin Okay, Alp Er S. Konukman, Ugur Akman. *Views on Turkey's impending ESCO market: Is it promising?* Energy Policy, Vol. 36 2008, pp. 1821-1825.

[6] Angelica Marino, Paolo Bertoldi, Silvia Rezessy. *Energy service companies market in Europe (status report 2010)*, Publications Office of the European Union, 2010. ISBN 978-92-79-16594-8. Can be downloaded from http://re.jrc.ec.europa.eu/energyefficiency/

[7] EMCA. *Development report of China ESCO industry in 11th five-year plan* (in Chinese), January, 2011. Can be ordered from http://www.emca.cn

[8] NDRC, MOF, PBC and SAT. Opinion for promotion of energy performance contracting and development of energy efficiency services (in Chinese), April, 2010. Can be downloaded from http://www.ndrc.gov.cn

[9] NDRC and MOF. Provisional administrative measures for public financing subsidy of energy performance contracting projects (in Chinese), June, 2010. Can be downloaded from http://www.ndrc.gov.cn

ESCO in Danish municipalities: Experience, innovations, potential

Jesper Ole Jensen, Danish Building Research Institute, Aalborg University

Jesper Rohr Hansen, Danish Building Research Institute, Aalborg University

Susanne Balslev Nielsen, Centre for Facilities Management, Technical University of Denmark

Abstract

This paper presents current research on Danish municipalities' use of ESCOs (Energy Service Companies) as a way to improve the standard of public buildings and to increase energy efficiency. ESCO has for many years been known as a way to realise energy efficiency in buildings. In Denmark, it has mainly been used in the industry so far, but in recent years more and more municipalities have taken up ESCO initiatives, in order to retrofit existing public buildings, and to make them more energy efficient. ESCO is in many ways a new way of collaboration for Danish municipalities, and therefore include many challenges. At the moment 15 municipalities (of 98 municipalities in Denmark) are involved in ESCO contracting.

The purpose of this paper is to discuss the various experience gained so far by municipalities, and to discuss the drivers and barriers behind the development. We also discuss whether ESCO might lead to new ways of working with energy efficiency in public buildings, and possibly generate innovation in the public sector. There is already some evidence from the municipalities that on-going ESCO projects have led to new ambitious initiatives and plans for energy savings in municipalities

ESCOs have received much attention in different Danish energy-.efficiency policies, where ESCOs are often described as a promising way to achieve energy savings in existing housing and to overcome barriers encountered by other attempts at energy savings. Instead of assessing ESCO only on the amount of energy saved, we suggest that ESCO contracting could potentially become a learning process for municipalities, enabling and encourage public administrations to work in other ways with public-private and public-public partnerships on energy savings. Theoretically, it will compare the Danish development with international ESCO experience as well as refer to public innovation literature. Combined with empirical case studies on ESCO contracting, we discuss factors and conditions that influence decisions on ESCO, the flexibility of ESCO contracts and whether it implies an innovative process, or as a possible contrast, a 'once in a lifetime-experience' for municipalities.

The paper is based on an on-going research project, which aims to identify the opportunities and barriers of applying ESCO in the Danish housing market. The results are therefore preliminary.

Introduction

Background

In a recent survey on the European ESCO market, it has been noted that the situation in Denmark has changed over the last years, primarily due a growth in municipal ESCO projects (Marino et al., 2010). In 2008 a handful of municipalities had started ESCO projects in municipal buildings, whereas in the beginning of 2011, 15 municipalities (of 98 municipalities in Denmark) have signed ESCO contracts or are preparing to do so. The experience gained by using ESCO are therefore still very new, and debates are still going on between municipalities on viewpoints and the pros and cons of ESCO contracting. Municipalities can be seen as locomotives for ESCO contracting in Denmark, and the municipalities' experience with ESCO is likely to influence the rest of the ESCO market. Therefore, it is interesting to look at the experience with municipal ESCOs so far, and to understand the drivers and barriers for the development in the municipalities.

As a general definition, an energy service company (ESCO) is a company that is engaged in developing, installing and financing comprehensive, performance-based projects (Vine, 2005). In an ESCO contract, the ESCO takes the risk for achieving defined energy savings, instead of the client (e.g. a building owner), making investments in energy savings measures more calculable and thereby attractive for clients. Practical definitions of ESCO however vary across Europe (Bertoldi et al., 2007). In the ESCO model used in Danish municipalities, the client takes the investment (i.e. no private or third-party financing), and the ESCO implements the agreed energy retrofitting initiatives, and guarantees a certain level of energy savings. 'Energy Performance Contracting' (EPC) would therefore be a more correct term to use, like in Sweden where similar types of contracts are used by the municipalities (Forsberg et al., 2007). As 'ESCO' however is used widely in a Danish context, the paper will also use this term. In the Danish context, 'ESCO' is used for the companies as well as for the types of agreements between the client and the provider. The agreements are generally and in this paper referred to as 'ESCO contract, ESCO agreement', 'ESCO collaboration' or as 'ESCO partnership'.

Purpose and methodology of the study

Our aim with the study is to identify drivers and barriers amongst the municipalities for using ESCO. This includes a question of whether the expectations that the municipality had to the ESCO have been met so far, and whether unexpected benefits, spin-off's or organisational innovations appeared as a result of the process. We therefore also discuss whether ESCO contracting represents new ways of working with energy-efficient retrofitting of buildings, for the municipalities.

Another interesting question in relation to understanding the market diffusion of ESCO is the flexibility of the ESCO concept; does it allow different contexts (political, financial, organisational, technical), and how innovative are the municipalities in adapting ESCOs to the municipal context? For instance, ESCO contracting might inspire the municipal facilities management-function (FM) to create innovation and new roles for the FM section, for instance in order to disseminate their ESCO experience to private house owners in the municipality. In the understanding of the context and the possible learning taking place, we therefore also focus on the municipal FM function, its organisation and its collaboration with other departments.

The paper is based on an on-going research project aiming to identify the potential and barriers to applying ESCO contracting in the Danish housing market; the results are therefore preliminary. The paper t presents findings from the initial phases of the project including a survey of existing Danish ESCO initiatives, literature studies of ESCO experience as well as a case study on one of the first ESCO contracting projects in a Danish municipality. Parts of the study are based on recent Danish and international surveys and literature studies on ESCOs and ESCO contracting. Other parts are based on interviews with eight municipalities about their motivation and experience with ESCO contracting. They were carried out as semi-structured interviews with leading officers in the municipal administration, based on an interview guide.

The institutional framework for ESCO in Denmark

On a national level, ESCOs have been promoted and encouraged in different policy papers on energy savings in the existing building stock. It is seen as an essential input for reaching international as well as national goals on energy savings and CO2 reductions (including the European 20-20-20 goals); 40% of the energy consumed on a national level is used to heat buildings, and as several surveys have documented, there is a massive energy saving potential in energy retrofitting of the existing building stock, but it has also been difficult to implement energy saving measures in the existing building stock.

As in other countries, the EU Directive on the Energy Performance of Buildings has been a driver for governments to encourage development of energy services (Bertoldi et al., 2007). As a first step, the Danish Government signed a political agreement in 2005 as part of the Directive, where the main objective was statutory energy labelling of both public and private buildings. To encourage energy savings, the municipalities were allowed to take loans for the renovation, if they included the suggestions for energy improvements outlined in the energy label for the buildings, as well as other specified energy reducing initiatives. Normally, municipalities are not allowed to start building projects by taking up loans, as a way for the state to keep municipal taxes under control. This also includes typical initiatives in an ESCO contract. Municipal loans typically have low interest rates and therefore third-party financing has not been interesting for the Danish municipalities in ESCO contracting. The guaranteed savings in the ESCO contract will cover the mortgages on the loan, and the municipality can therefore complete energy renovations as expense neutral. This is the main ‘carrot’ for the municipalities to engage in ESCO projects, and thus energy labelling of municipal buildings plays an important role. To strengthen this, an agreement from 2007 between Local Government Denmark and the government settled that all initiatives for energy efficiency with low payback time (< five years) outlined in the energy label on public buildings should be completed within four years.

Experience shows that besides formal regulations, institutional capacity building can be an important tool for developing an ESCO market (Bertoldi et al., 2007), as for instance in Austria and Sweden. In Sweden, the formation of an Energy Performance Contracting (EPC) forum was formed in 2004 with the aim of creating contact between public building owners, consultants and ESCO companies, and communicating experience, as well as collecting and communicating experience gained from EPC contracting. Evaluations have later shown that the EPC forum has had a central role for the development of EPC in Sweden, by informing different actors about EPC and creating confidence in the concept (Forsberg et al., 2007).

In Denmark, such institutional capacity building has not taken place as a coordinated effort, but different initiatives have contributed to it. Besides a general promotion as a tool for energy reductions in buildings, it has also been promoted by the Ministry of the Interior and Social Affairs as a way to increase public-private partnerships (PPP). This effort includes workshops with private and public partners to promote networks and to disseminate of knowledge, support to municipalities that consider ESCO contracting, action plans for public-private collaboration, collection of knowledge and 'best practice' etc. On another track, the ‘Centre for Energy Savings’, a publicly financed unit with the aim of promoting energy savings in general, has promoted ESCO, by disseminating knowledge of ESCO, monitoring development and experience in Danish municipalities, informed on ‘best practice’ etc. Finally, the ‘Energy Research Programme’ has initiated a number of R&D projects on ESCO, for instance on describing the elements in ESCO, experience from other countries, developing a standard contract on ESCO etc. Compared with the Swedish strategy, which had a much stronger international perspective, the Danish strategy has been less internationally oriented. The primary international flavour has been the compilation of international experience (primarily Sweden, Austria and US), and actors’ own experience from abroad (primarily Sweden). The formation of a Swedish forum on ESCO has apparently been given a more continuous platform for exchange of knowledge, whereas the Danish initiatives have been of a shorter duration (for instance workshops between ministries, municipalities, ESCO consultants, and ESCO suppliers).

Moreover, as a contrast to the Swedish development, the climate agenda has been an important motivation for many municipalities, especially voluntary agreements. One is the ‘Climate Municipality’, a voluntary agreement between the municipality and the Danish Nature Saving Trust, which obliges the municipality to reduce energy consumption by 2% per year in the municipality as a whole, i.e. not just the municipal administration, but the municipality as a defined area, including private building owners. This includes not just energy for heating of buildings but all kinds of energy, including supply, transport, electricity etc. At the moment, about 2/3 of all Danish municipalities have signed such an agreement. Another voluntary agreement is the ‘Curb-cutting agreement’ with the Centre for Energy Savings in which the municipality promises to reduce electricity consumption in public buildings by 2% per year.

ESCO in Danish Municipalities: An overview

Table 1 lists the ten Danish municipalities that have signed an ESCO contract, including the main characteristics of the contract. In the following we briefly describe the development, the actors and the type of projects.

Table 1. Status for ESCO contracting in Danish municipalities as per 7 January 2011. Source: Danish Energy Savings Trust and interviews with municipalities. Besides these ten municipalities, another five municipalities are preparing ESCO contracts.

Municipality	Volume in ESCO contract	ESCO supplier	Contract period	Investment, € / m^2	Guaranteed Savings	Improvements of:
Kalundborg	10 buildings 30,000 m^2	Schneider Electric	2009-2021	89	21%	Technical system and installations
Middelfart	100 buildings 190,000 m^2	Schneider Electric	2008-2015	31	20%	Installations and indoor environment in all municipal buildings and re-insulation of a few buildings. Energy labelling of all buildings
København	27 buildings 68,000 m^2	DONG	2009-2018	24	n.a.	Energy savings and energy labelling of properties in the nursing facility “De Gamles By”
Gribskov	100 buildings 190,000 m^2	Schneider Electric	2009-2016	18	17%	Energy savings through better management and technical improvements of buildings
Vallensbæk	20 buildings 93,000 m^2	Dansk Energi Management	2009-2019	50	31%	Technical systems and building envelope for the municipal buildings. Energy labelling
Kerteminde	48 buildings 117,000 m^2	Schneider Electric	2009-2019	51	n.a.	Technical systems and building envelope
Høje Taastrup	270 buildings 270,000 m^2	Schneider Electric	2009-2021	20	18%	Technical systems, indoor environment in all municipal buildings and better heat regulation
Halsnæs	120 buildings 175.884 m^2	YIT	2009-2021	70	30%	Installations and building envelope as well as incentives for users to savings
Greve	11 schools 100,000 m^2	Siemens a/s	2009-2016	22	16-19%	Better heat regulation, ventilation and lighting in schools and kinder gardens
Sorø	65 buildings 133,000 m^2	Schneider Electric	-	44	n.a.	Energy systems and building envelope for all municipal buildings

Different stages
The municipalities are at different stages; some are in the initial phase of preparing a tender, whereas others have finished retrofitting and have entered the operational phase. The first Danish municipality to sign an ESCO contract was Kalundborg in 2006. Due to the municipal structure reform in 2007, the collaboration was delayed, but re-started in 2009. Meanwhile, two other municipalities, Gribskov and Middelfart, had started their ESCO projects. These three municipalities formed their own ‘ESCO network’, with close collaboration and knowledge-sharing in the initial phases, leading to several ideas on how the ESCO concept could be disseminated to other municipalities. In 2009 and 2010, several other municipalities (at the moment 15 municipalities) have signed ESCO contracts. The projects are typically divided into three stages: Energy audit (incl. energy labelling), implementation and operation. Typically, the contracts give the municipality the option to cancel the collaboration after each stage. This often gives the municipal decision-makers more confidence to sign the contract, as a collaboration lasting 10-12 years may be difficult to predict, especially when municipalities rarely know the ESCO supplier beforehand.

Market actors
In contrast to many other European countries, where utilities have been the main providers of ESCO services (Bertoldi et al., 2007), the Danish market has been dominated by private companies that gained experiences from ESCO contracting in neighbouring countries, primarily Sweden. It should be noted that a

single ESCO supplier (Schneider Electric) has a large share of the market (approx. half of all contracts so far), although several other ESCO suppliers have been present on the market for some time. Several consulting companies have developed competences on ESCO, and taken on the role of consultants for the municipalities on designing the tender and the contract on the ESCO collaboration. The utilities have not played a large role in developing ESCOs in the municipalities, but have instead focused more on developing ESCO-like concepts for private home owners (including the so-called 'ESCO light').

Type of projects
There is a large variation in the number of buildings included in the ESCO contracts (from 10 to 270), with an average of 60 buildings (or 114.000 m^2) per contract. Moreover the size of investments in the buildings varies, from 18 €/ m^2 to 89 €/ m^2, with an average of 37 € /m^2. These figures are comparable with those of Sweden, where the average building volume for EPC contracts is 140,000 m^2, and investments typically are around 35 €/m^2 (Wormslev, 2008). In all cases the contracts are based on the guarantee model; the municipalities finance the retrofitting, and the ESCO guarantees a certain energy reduction, based on the retrofitting initiatives defined in the contract. If the reduction is not reached, the ESCO will pay the municipality the difference. If more than the guaranteed savings are reached, the municipality and the ESCO will share the surplus according to conditions defined in the contract. The guaranteed savings are typically ≥ 20% of the existing energy consumption. Improvements on regulation and control (for instance introducing CTS, and equipment for steering and monitoring) that allow energy use that often have a short payback period (small costs and high energy savings), whereas improvements that include the physical improvements of the building (e.g. new windows, insulation or other improvements of the building envelope) have longer payback periods and therefore are often kept out of the contracts. It is, however, possible to define a combination of regulation improvements and building improvements, which some municipalities have already done. These differences are partly reflected in the various guarantees for energy savings in the contracts, ranging from 16-17% to 30-31% reduction of the energy budget in the municipal buildings, with an average of 22%.

Drivers and barriers for using ESCO

Compared with the high expectations to the ESCO concept as a tool for providing more energy-efficient retrofitting of public buildings, the limited number of municipalities using ESCO is often described as 'disappointing' and 'a failure for the government'. In contrast, others describe the ESCO market as 'coming and 'evolving', as many municipalities are interested in the concept, and the number of municipalities signing ESCO contracts is increasing. This illustrates different viewpoints on the development, and that there are ongoing discussions amongst Danish municipalities about the possible benefits of using ESCO projects. In the following, we take up some of the potential drivers and barriers discussed in the current debate on ESCO, as well as drivers and barriers taken from the international literature on ESCO, and discuss this in relation to observations made from interviews and studies on municipalities engaged in ESCO contracting.

Energy labelling
As mentioned in the Introduction, energy labelling of municipal buildings is a cornerstone for promoting ESCO contracting. However, many municipalities have not completed the energy labelling of their buildings yet. A survey from December 2009 showed that at that time only 30% of municipalities had completed the energy labelling (KL, 2010). Therefore a central motivation for completing the retrofitting of the buildings has been missing; the municipalities have less overview of the buildings, their energy consumption and their savings potential, and also have no access to take up loans for financing the retrofitting. A survey on ESCOs in Danish municipalities showed that many municipalities find it hard to find financing for energy savings in buildings (IDA, November 2010), which could be related to the lack of energy labelling. On the other hand, data from the municipalities show that energy labelling of the municipal building portfolio is included in many ESCO contracts. Thus, the demand for energy labelling of municipal buildings might actually work as a driver for ESCOs, although not in the intended way. The outcome of the energy labelling can also be argued; the labelling system has been heavily criticised for not delivering value for money and some municipalities share this viewpoint. *"We started labelling our buildings four years ago, and what did we get for the money? We learned that we did not reduce the energy just by labelling the buildings"* (officer, municipality of Høje Taastrup). Nevertheless, this led to considerations on other ways to save energy, and this is where they started to take an interest in ESCO. Other municipalities have similar stories; energy labelling is a mandatory

first step to learn about energy savings in municipal buildings, and in this exercise ESCO contracting seems to be a possibility.

Financing
A main reason for the municipality to enter an ESCO contract is the possibility of financing the improvements of many buildings over a short time. If the municipality should finance the renovations traditionally, there would only be room for gradual improvements, due to municipal budget limitations. In an ESCO project the municipality is allowed to take out loans for the entire project at the same time, as the ESCO supplier guarantees the savings. For instance, one municipality states that it could have had 1 million Dkr. per year (130,000 €) over the coming years, but the ESCO contract gives them 68 million Dkr.(9 million €). For some municipalities it might be the only reason, as they see themselves as capable of completing the building improvements themselves. *"Naturally, if we had had the 70 million. Dkr. ourselves, we would have done it, because we would have had the savings in cash afterwards"* (officer, municipality of Høje Taastrup).

The counter argument to the attractive financing options is that '*ESCO is too expensive'.* A survey from 2010 showed that the main reason for municipalities not to enter ESCO contracting is a better economy by doing it yourself, i.e. that the ESCO arrangement is too expensive; 82% of the municipal directors claims that in terms of economy it is better to finance the improvements in other ways than as an ESCO contract. Nevertheless, such financing is difficult to find, and it is an open question what the alternative to ESCO financing there is. One possibility, as indicated in the quote above, is municipal equity, another is funding it out of the ordinary budget, but this would be possible only for major municipalities.

The question of ESCO's being expensive is not a question raised by municipalities that have already signed a contract. The municipalities accept that the ESCO suppliers earn money on the contract, but the main argument is that the ESCO allows an instant improvement to take place. Another aspect concerns the administrative capacity to carry out the building improvements. This is usually not mentioned in the discussion of the pros and cons on ESCO, but it is very important for especially the smaller municipalities that do not have the staff to complete such a large task. As one municipality explains: *"It would take a long time to establish an organisation that could manage an assignment like that, and we would have to start to downsize it almost as soon as we had started"* (officer, municipality of Vallensbæk). In a similar way, other municipalities state, that it would have been completely impossible to carry out such a task with their staff, which is usually very small. Keeping this task in-house therefore, for many municipalities, require a major re-organisation, which would in many cases be unrealistic.

Political commitment
Surveys on municipal engagement in ESCO have indicated that municipalities that have signed up as 'Climate Municipality' are more interested in ESCO and have a more positive attitude towards it than other municipalities. Our interviews indicate that the 'Climate Municipality' as well as the 'Curb-cutter' deal present great challenges for the municipalities, but also a political acceptance to pursue energy savings. Reducing energy consumption by 2% p.a. is a challenge that requires extraordinary initiatives: *"We could save 2% a couple of years, using our own municipal finance. But after that it would become difficult. 2% per year is actually very ambitious…but then one of our consultants mentioned ESCO as an opportunity"* (officer, municipality of Halsnæs). On the other hand, there are also examples of using ESCO in municipalities that are not politically very engaged in the climate agenda. Here, ESCO is seen as a way of being able to do something on energy retrofitting, without having to engage very much in it. *"If you had politicians that were really engaged, then you were already rolling, and you just needed to go on, instead of starting from scratch. But in our case it is better with an ESCO project, then you can see what you get for your money"* (officer, municipality of Kerteminde).

Energy-saving potential of buildings
In some municipalities the potential for energy savings is too small for an ESCO due to well-maintained buildings. In general, however, Danish public buildings have a large back-log on maintenance, and a survey found that 25% of public managers assess the energy standard of municipal buildings as 'low' or 'very low' (IDA, 2010), which suggests a large potential for the retrofitting of the municipal buildings. The contracts from the present ESCO municipalities show that there is room for flexibility in defining how poor standard of the buildings has to be to be included in the ESCO contract. In one municipality, the preparations for ESCO contracting showed that the buildings were in better shape than expected, which made it difficult to find the 15% energy reductions that were the aim. Therefore, the municipality had to *'climb up the tree for the high-*

hanging fruits', for instance by including solar panels on the town hall in the contract. The city council had to accept that the payback period was raised from 15 to 20 years, which according to the officer was a great challenge.

If only the buildings with the greatest potential are included, and only simple improvements are made, it is possible to reduce the payback time and reduce investments. If, however, more buildings are included and ambitions are raised regarding building improvements, payback time will rise, and so will the investments. The benefit is that more buildings are included, and the total amount of energy savings will increase. Therefore many municipal officers argue that once the politicians have accepted the ESCO strategy, as many buildings as possible should be included in the contract. This will allow not only energy reductions to be reached, but it would potentially improve the indoor climate and reduce the maintenance backlog. Therefore many municipalities try to get as many buildings as possible included, so that the initiatives with short payback time will 'finance' initiatives with long payback times. This is a difficult balance that the municipalities have to find, as expressed by this officer in Sorø: *"…it takes many improvements with short payback periods to enable inclusion of windows, walls, doors and all the other things with a long payback period."* (officer, municipality of Sorø).

It is not an easy task to decide how the tender should be structured, and the concept might be changed along the way, as the officers learn about the possibilities and get input from discussions with other stakeholders in the municipality. As an example, one municipality started out with a conservative aim of 15% savings that they were certain that they could find. However other stakeholders raised the question, why the goals were not more ambitious, if some ESCO supplier said they could save for instance 30%. This led to a new project description, with more ambitious goals, including that 15% of the reductions should come from renewable energy, and 35% from improvements of the building envelope. This illustrates that in the course of the process of defining the project, there is room for flexibility and for being innovative with regard to the types of buildings included. Defining the potential is therefore not a simple question, but depends of the strategy and the political commitment in the municipality.

Keeping competences in-house

One of the main reasons for the reluctant attitude amongst some municipalities, as also mentioned by Bertoldi et al., (2007), is the alternatives to ESCO regarding energy retrofitting. One of the main arguments against ESCO is that it is more profitable for the municipality to complete the energy-efficient retrofitting themselves, as an in-house project (IDA, 2010; NRGi, 2009) and that they are sceptical about the financing mechanisms in the ESCO arrangement. Many also argue that if the municipality itself completes the energy-retrofitting, competences will stay in-house. "*The companies offering ESCO-contracts with the municipalities want to get a hold on the long end, and we are not interested in that*" (quote from a leader of the building section in a municipality who has rejected an ESCO collaboration). As an alternative, the municipality might finance a systematic retrofitting with its own resources, they might start a strategy with private companies on reducing energy demand in the municipal buildings, or other types of arrangements. The argument for keeping competences in-house might also reflect more ideological views on public-private partnerships. However, in practice the option for an in-house strategy is limited to the larger municipalities with bigger staffs, more competences and better economic resources. As our interviews also show, for smaller municipalities this is practically impossible.

Lack of knowledge

An often mentioned barrier in a European context is lack of information and understanding about ESCO (Bertoldi et al., 2007). These are, however, rarely mentioned as a barrier in the Danish debate. Different surveys have demonstrated that very few municipalities mention lack of knowledge of ESCO as a reason for not using ESCO (IDA, 2010; NRGi, 2010). There has been no evaluation of the Danish efforts to promote ESCO on a national level and whether this has motivated the municipalities. In our interviews with the municipalities, no one mentioned the national supportive initiatives, but all referred to other reasons and stories for being involved. This includes information and knowledge about ESCO from different informal sources, for instance talking with other municipalities, meetings with ESCO suppliers, from the media and others sources. Some Danish municipalities have also visited Swedish and German municipalities to learn from their experience. At the time when the Danish market emerged in 2007, about 20 Swedish municipalities had already signed an ESCO contract. Many ESCO providers (Schneider electric, Siemens, YIT etc.) have built their competences and gained experience on the Swedish market, and applied it on the

Danish market. This has given Danish clients (municipalities) more confidence in using the ESCO model, as the providers could refer to cases from similar municipalities in Sweden.

Transaction costs
Transaction costs is another well-known barrier tor ESCO (Bertoldi et al., 2007) and PPP in general. If transaction costs rise, e.g. related to due diligence or to contract formulation, the volume of the contract also needs to be proportionally higher to maintain the net benefit. The minimum volume for an ESCO project in the Danish context is assessed to 10-15 million Dkr. (1.5-2 million €) (IDA, 2010). This has rarely been discussed as a problem in the Danish ESCO debate. One reason for this might be that the municipal reform in 2007 reduced the number of municipalities in Denmark from 279 to 98, increasing the average size of a municipality to approx. 50,000 inhabitants, and also increasing the municipal building stock. This makes it easier for the municipalities to send a large volume of buildings to tender, thereby reducing the transaction costs. The average ESCO project is approx. 5.5 million € in volume, and therefore well beyond the critical limit of 2 million €. Other types of transaction costs involve the legal aspects of the tender and the contract. In a survey, 10% of the technical directors mention the legal challenges of ESCO as a barrier to using ESCO, and 8% mention the process of tender as a reason for not using ESCO. As an example, one municipality in a survey states that "*the legal aspects about the guarantee for energy savings are often complicated and require vast amounts of documentation in order to work*" (IDA, 2010).On a regulatory level, the initiatives to reduce transaction costs have been limited. A standard contract for municipal ESCO's has been developed (Elsparefonden, 2009), but we have no reports on municipalities actually using it. The question of transaction costs was not brought up by any of our informants during the interviews, but the legal challenges were mentioned by many. This especially concerns the tender, where most municipalities use consultants. Especially the limitations of EU tenders that do not allow up-scaling of a project without a new tender were mentioned by several municipalities as an important issue to be aware of.

Analytical perspectives: ESCO and Innovation

As indicated in the sections above, ESCO contracting implies many challenges for the municipalities, which might lead to new ways of working with energy savings in buildings, with end-users, with public-private partnerships or different ways of organising the municipal administration.

A theoretical model of innovation
In order briefly to get an understanding of innovation as a phenomenon, some definitions are appropriate. Van de Ven (1999) defines innovation in general as "*new ideas that are developed and implemented to achieve desired outcomes by people who engage in transactions (relationships) with others in changing institutional and organizational contexts." (Van de Ven 1999:6).* Jean Hartley (2005) defines innovation in the public sector as follows: "*Those changes worth recognizing as innovation should be…new to the organization, be large enough, general enough and durable enough to appreciably affect the operations or character of the organization* (Moore *et al.*, 1997, p. 276, quoted from Hartley 2005). And finally, Albury defines innovation in the public sector as follows: *"Successful innovation is the creation and implementation of new processes, products, services and methods of delivery which result in significant improvements in outcomes, efficiency, effectiveness or quality (Albury 2005: 51)."* What the definitions have in common is that innovation is *the creation of new ideas that are developed and implemented in the form of new processes, products, services and methods of delivery, in order to achieve desired outcomes, which, in case of success (!), will result in significant improvements in outcomes, efficiency, effectiveness or quality.*

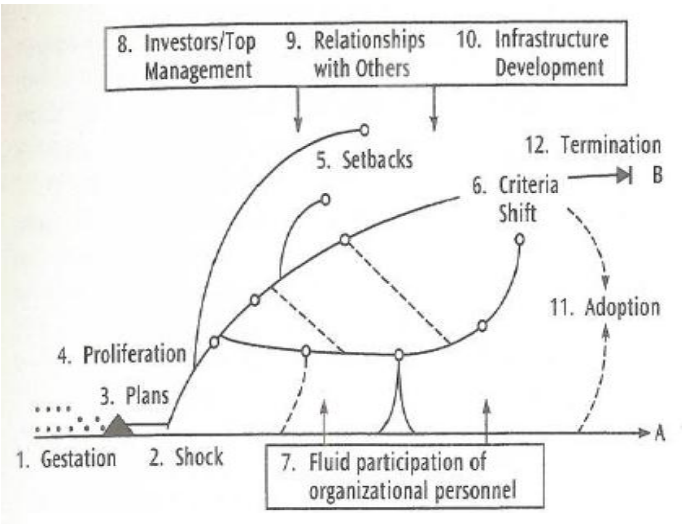


Figure 1. Key components in the innovation journey. Source: Van de Ven, 1999.

However, each of the above authors stresses some central aspects worth mentioning regarding innovation in the public sector. First of all, Van de Ven emphasises the *process* aspect of innovation, which to a very high degree is characterised by confusion, constant change, and uncertainty: “*The journey is an exploration into the unknown process by which novelty emerges. The process is characterized as inherently uncertain and dynamic, and it seemingly follows a random process”* (1999:3). As an illustration of this seemingly random dynamic in innovation enterprises, Van de Ven uses Figure 1. Figure 1 shows us ‘the innovation journey’ from the left to the right. Of importance is the constantly changing environment of the innovation (Figure 1, Nos. 7-10), whereas the development and implementation process is characterised by numerous setbacks but also a proliferation of spin-off opportunities (Figure 1, Nos. 3-12). What the research (mainly from the private sector) demonstrates is that innovation is to a large extent a matter of taking risks; and that the plausibility that the innovation project might fail, is an acknowledged condition in the private sector. So, it seems plausible to suggest that what *drives* the innovation forward according to Van de Ven is the uncertainty and challenges in the innovation process, which forces the participants to be creative in problem solving – but also forces the participants to think in new development and spin-off opportunities, based on the learning generated in the process.

Hartley (2005) stresses the fact that innovation in a public sector context should to some extent be radical in order to distinguish innovation from the usual organisational improvements (see Figure 2). But she also stresses that innovation enterprises in the public sector is often more constrained than in the private sector, in that it also has to yield visible improvements (square 4 in Figure 2). Hartley suggests that the main driver for innovation these days is the dynamic of networked governance. Compared with hierarchy and new public management, network governance steers through networks (Hartley 2005:30). Though Hartley does not define networked governance, she states that network governance revitalises the leadership roles in the public sector, and forces managers and their frontline staff to take on the role of the ‘explorers’ (ibid.: 29). Summarising the growing literature on network governance, Sørensen & Torfing (2005: 15) define network governance as ’a relatively stable horizontal interfacing of interdependent, but operationally autonomous actors, 2) that interacts and tries to influence each other through negotiations, 3) that takes place in an institutionalised community, 4) that is self-regulating within a framework defined by the political authorities and 5) in a broad sense contributes to public regulation’.

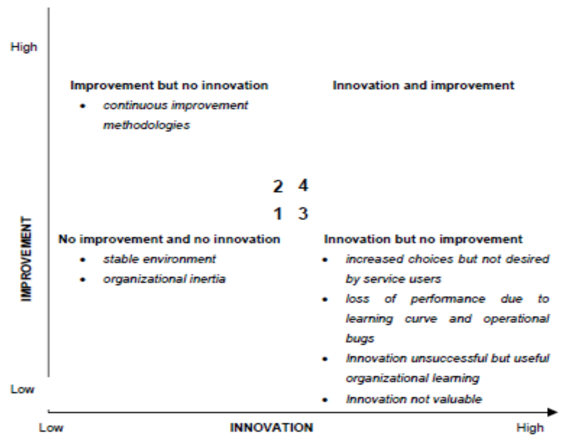


Figure 2. Innovations and improvements. Source: Hartley, 2005.

In other words: network governance forces the public sector to facilitate networks of otherwise un-coupled actors and to design the network as a set-up where these actors can pursue their own interest, and at the same time contribute to the political goal achievement of the public agency. This is both a substantial, organisational and strategic challenge.

Analysis: ESCO innovation in local government?

Innovation theory helps us identify an innovation phenomenon, that is, which dynamics to expect in the innovation process, and what role to play as a local government actor in order to create opportunities for innovation to occur. But it cannot tell us anything about what the desired outcomes are for local governments, how to measure their degree of success on an innovation scale, and what the potential barriers are. Therefore, we need to adapt innovation to an ESCO context in order to establish an innovation scale for ESCOs in Denmark. The experience gained in Denmark hitherto shows us that it is possible to use ESCO as an innovation platform that creates both improvement and innovation (Hartley 2005), but that this is definitely not the standard option for most local governments. We will discuss possible innovative changes in the municipalities’ practice and understanding, having applied the ESCO model. However, as Danish municipalities have just recently begun their ESCO collaboration, which typically lasts for a period of 12-15 years, the experience is so far limited. Nevertheless, there is already some evidence from the municipalities that ongoing ESCO projects have led to new ambitious initiatives and plans for energy saving in the municipality.

When analysing the practices of Danish local governments from an innovation perspective, it is possible to place them on a tentative innovation scale:
Step 1: improvements achieved, but no innovation
Step 2: Improvements achieved as well as small-scale spin-offs, but no innovation
Step 3: Improvements achieved as well as innovation, but no successful innovation

By 'improvements' we mean what the standard desired outcomes are for local governments using ESCO: Reductions in energy consumption, energy labelling of municipal buildings, competences transferred to the end-users – but also regular building renovation. By 'innovation' we mean a challenging, confusing and perhaps spin-off rewarding adaptation process, where local government take on the roles of explorer and network facilitator, which may lead to achieved outcomes and improvements otherwise not possible.

Step 1: improvements 'yes', innovation 'no'

What characterises this group of municipalities at this stage is a routinised project approach to the ESCO enterprise, following this line of reasoning: "ESCO is just one project out of many others, the process has been relatively predictable, nothing unexpected has happened so far, we manage the process by hiring advisors, which more or less guarantees that the ESCO project delivers as planned." As a civil servant stated when asked about surprises in the ESCO project: *"No, nothing really unexpected occurred, everything has been working very smoothly (…) We are a very small municipality with only 16,000 citizens, and we have a high degree of outsourcing*" (officer, municipality of Vallensbæk). This illustrates that for some municipalities, ESCO can appear as another outsourcing service on offer, which is similar to existing municipal practices.

In an innovation perspective, we can argue that municipalities approaching ESCO in this way get what they want, but nothing more. That is, they do not get new development opportunities, and ESCO as a concept does not lead to any reflections on reconsidering 'business-as-usual'. The reason for this might be that all the disturbing and challenging elements (Van de Ven, 1999) have been 'outsourced' to the ESCO and legal advisors. In this way, no capacity building or learning are created within the local government organisation. One barrier for organisational innovation and learning thus turns out to be the outsourcing of challenges to advisors and ESCO, a conclusion that corresponds well with the experience of municipalities that do the energy-retrofitting themselves: they want to keep the project and the capacity-building process 'in-house'. In fact, it seems that one municipality has had this experience: *"We've handed it over to the ESCO, and the ESCO has made a project description. But we have not had the knowledge of the details, I would have liked a little more insight in what they actually did with our buildings. If we were to do it again, we would need to have better insight into what actually needs to be done"* (officer, municipality of Kerteminde). Another barrier to innovation mentioned by one of these municipalities was that they did not have the resources for developing the ESCO as a project any further. Typically, municipal officers are busy taking care of the ESCO and their FM assignments, and have no time or resources for developing innovative concepts. This finding corresponds with Mulgan & Albury (2003), stating that one of the main drivers for innovation in the public sector is access to funding for experiments.

Step 2: Improvements achieved as well as small-scale spin-offs, but no innovation

Municipalities are placed on this step mainly due to their creative and pro-active ways of using ESCO. As an example, the municipality of Halsnæs had been on a study trip to Sweden thereby learning about the importance of communication aspects in user involvement, and about the best way to involve users as well as their wishes for renovation. The Halsnæs municipality is also considering motivating technical staff and users to be ambitious about their 'energy-saving' education by collaborating with a local business school, thereby giving them a certificate. Finally, as a part of the contract with ESCO, Halsnæs has demanded that a fixed percentage of future energy consumption should be covered by green energy, thus resulting in the construction of a solar cell plant. This creativity led to a new development opportunity that could be used to fuel the cars of the nursery staff in the municipality Another municipality (Høje Taastrup) has been creative in using ESCO as a means to reach several political ends. The municipality of Høje Taastrup is first of all one of the Danish 'Climate Municipalities', and ESCO could be seen as one of the first steps to reach the climate goals in 2020. Second, another political aim was to create a better indoor climate in all public buildings, and

ESCO is doing just that. Finally, because of budget constraints, only self-financing projects are to be launched in Høje Taastrup, and ESCO also satisfies this demand. An unplanned spin-off opportunity was that due to ESCO the municipality could afford to upgrade a significant part of their buildings to zero-emission buildings, which would otherwise have had to be postponed. This was possible because of a competent and resourceful staff that as part of ESCO gained an unprecedented knowledge of their building. In conclusion, one might see municipalities on this step as having a more creative 'in-house' grip on the ESCO project, which has made it possible to connect the ESCO project with other strategies. However, none of the referred municipalities have to this date any ambitions of extending the ESCO concept, for instance to include other types of buildings or facilities, or even use the experience to involve private building owners in ESCO arrangements. The reason for this might be that these municipalities are in a time-consuming implementation phase. But also that it is quite resource-demanding to involve homeowners and private parties in such activities.

Step 3: Improvement and innovation – but with some challenges

An example on an innovative approach to ESCO is the municipality of Middelfart, where the successful ESCO-retrofitting of the municipality's building stock has led to a dissemination of the ESCO concept to other areas of the municipal administration. The municipality has tried to 'copy' the functions of an ESCO to also encompass private homeowners' buildings by establishing a network with local and regional actors (energy suppliers, carpenters, plumbers, financing institutions and others) that could offer the homeowners an 'energy-saving package' consisting of a free energy audit of the house (inspired by the energy label) and an offer to implement the initiatives with low payback time. In contrast to a 'real' ESCO, this did not include guaranteed of energy savings. The idea was to make homeowners in different neighbourhoods give a collective tender on energy renovations of buildings that are technically similar. In doing this, the municipality took on the role of the explorative leader, a strategy of network governance (Hartley 2005). The advantage of a possible success would have been a heavy reduction of CO_2 emission as well as employment for local business. However, pooling home owners in a rural environment proved more difficult than expected; the network governance may have a reduced effect in rural settings compared with urban areas, maybe because the 'sampling' density of similar buildings varies. Therefore, different concepts for engaging the local homeowners has subsequently been developed and tested. Nevertheless, this initiative and the municipal ESCO are embedded in a vision for the municipality, where the strategy is to build competences amongst the local enterprises for energy renovation, and doing this in networks with other municipal actors. Also, initiatives are being taken to encourage other building owners (for instance social housing associations) to implement energy savings, inspired by the municipal ESCO project.

In conclusion, the municipality of Middelfart has so far been the most innovative municipality, primarily because the municipality learned important lessons from the ESCO, which it afterwards tried to copy by applying a network governance strategy. It is important to note that Middelfart has taken some of the first important steps to think creatively about using ESCO to reduce CO_2 emission in the entire building stock of the municipality, and that one of the drivers in this innovation process was the access to external funding, which provided Middelfart with the resources necessary for experimenting.

Conclusions

Our preliminary studies of the ESCO development in Denmark suggest that ESCO as a concept holds great potential for flexible interpretations, i.e. that it can be formulated and argued in many different ways to fit the local context. What seems as a more or less uniform concept is revealed by a closer look to have many different drivers and logics for the municipalities. This includes issues on financing, on political commitment to pursue energy reductions, on defining the ESCO tender and composing different types of initiatives in buildings, issues on competences and the internal municipal organisation, and the traditions of carrying out public-private collaboration. The flexibility of ESCO might to a large degree decide to which extent the concept will be applied more generally in Danish municipalities.

We observed that the national initiatives for institutional capacity building on ESCO seem to have had limited influence on the municipalities' knowledge of and decisions on ESCO, and have been relatively weak compared with those of other countries. They might however have had an effect on the supply-side amongst ESCO suppliers and consultants, but this has not been studied. The limited institutional capacity building might have had an influence on the development, but we also observed that the municipalities have collected information on ESCO from other informal sources that have helped them in their decision to take up ESCO contracting. To a large extent, the development in Denmark has benefited from the development in other countries, primarily Sweden, on the supply-side (ESCO suppliers having gained experience from projects in Swedish municipalities), as well as the demand-side (Danish municipalities learning from Swedish municipalities). Compared with the Swedish development, the local commitment to reaching agreed energy savings has been a strong motivation for the Danish ESCOs, along with the mandatory energy labelling being linked to the opportunity for loan-taking for energy renovations.

An interesting issue is raised on completing energy renovations as ESCO projects versus as an in-house project, thus keeping competences within the municipality. Smaller municipalities have limited options for the latter solution, but for large municipalities this might raise a dilemma that defines the future role of the municipal administration; to what extent should municipal competences concern hands-on knowledge on building management, including energy reductions, and to what extent should the competences concern management of out-sourcing, public-private partnerships, networked governance etc.?

Our analysis also suggests that ESCO contracting implies potential for public innovations, as learning taking place in the process can be exploited in different arenas, giving the municipality new roles, for instance as performing network-based governance in relation to local actors outside the municipal administration. We therefore see ESCO not only as an option to pursue goals on energy reductions and maintenance back-log, but also as a way to develop municipal administration in more innovative directions.

References

Albury, D. (2005) "Fostering Innovation in Public Services", *Public Money & Management, vol. 25, no. 1, pp. 51*.

Bertoldi, P., Boza-Kiss, B., Rezessy, S. (2007), *Latest Development of Energy Service Companies across Europe – A European ESCO Update.* European Commission – Institute for Environment and Sustainability, Italy.

Elsparefonden (2009) *"Standarddokumenter for udbud af energitjenester".* Version 02, 2009-03-26.

Forsberg, A; Lopes, C; Öfverholm, E. (2007) *How to kick start a market for EPC. Lessons learned from a mix of measures in Sweden*. ECEEE 2007 Summer Study.

Hartley, J. (2005), "Innovation in governance and public services: past and present." *Public Money and Management, 25(1),* pp. 27-34.

IDA (Ingeniørforeningen i Danmark) (2010) *Survey on energy savings in the municipalities with ESCO*. November 2010

Kommunernes Landsforening (KL), 2010: *Kommuner sparer på energien*. Available at: http://www.kl.dk/Artikler/70085/2010/04/momentum2010-4-6/,

Marino, A.; Bertoldi,P.; Rezessy, S. (2010) *Energy Service Companies Market in Europe - Status Report 2010.* Institute for Energy. EUR 24516 EN – 2010.

Moore, M. H., Sparrow, M. and Spelman, W. (1997), Innovation in policing: From production line to jobs shops. In Altchuler, A. and Behn, R. (Eds), *Innovation in American Government* (Brookings Institution, Washington, D.C.).

Mulgan, G. and Albury, D. (2003) *Innovation in the Public Sector.* Prime Minister's Strategy Unit, Cabinet Office, discussion paper, available at: www.strategy.gov.uk/downloads/files/pubinov2.pdf (accessed 7 March 2006).

NRGi Rådgivning A/S (2010) *Undersøgelse af det kommunale arbejde med energibesparelser og udbredelsen af ESCO.* Available at: http://www.goenergi.dk/aktuelt/offentlig/kommuner-flirter-med-esco

Sørensen, E. & Torfing, J. (2005) *Netværksstyring: fra government til governance.* Roskilde Universitetsforlag.

Van de Ven, A.H. (1999) *The innovation journey*. Oxford University Press, New York.

Vine, E. (2005), "An international survey of the energy service company (ESCO) industry", *Energy Policy 33*, 691-704

Wormslev / NRGI (2008) *Energitjenester – en ny form for partnerskabsaftale om energieffektivitet. Baggrundsrapport for elsparefondens projekt om Udvikling og afprøvning af ESCO-koncept i kommunale bygninger*. Frederiksberg, 2008.

Retail Margins on Energy Efficient Appliances

Larry Dale, Hung-Chia Yang, Sydny Fujita

Energy Analysis Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory

Abstract

As energy efficiency standards for household appliances have become more stringent, understanding the impact of higher standards on appliance retail prices is increasingly important in assessing changes to consumer welfare. This paper uses simple supply-demand models to examine the behavior of retail prices in different market conditions. We apply these models to explain the recent behavior of retail prices in four U.S. markets: oil and gas, real estate, lumber, and electronic goods. We conclude that retail margins closely reflect changes in the cost of supply, so that appliance standards affect retail prices to the degree that they affect retailers' costs.

1 Introduction

Improving energy efficiency for residential appliances through mandatory energy efficiency regulations has become a widely-adopted method of reducing carbon emissions and energy demand in many countries. The welfare impact of these standards depends critically upon the retail price effects of the standards. The retail price of efficient residential appliances may exceed the price of baseline, less efficient appliances, due to differences in manufacturing costs, retail costs and retail margins.

Policy interest in recent years has focused on the effect of changes in appliance efficiency on retail margins—the topic of this paper. Final rules for many residential appliances published by the U.S. Department of Energy are one manifestation of the influence of retail margin estimation on policy decisions. Some parties to the debate have argued that retail margins are generally fixed in proportion to manufacturing costs. This would imply generally large retail price increases following the imposition of energy efficiency standards, thereby lowering the benefits consumers derive from standards. We contend, however, that this is not likely given the nature of the appliance market and cost structure.

2 Retail Margins and the Consumer Benefits of Appliance Efficiency Standards

We begin with a discussion of the policy ramifications of different assumptions about retail margins (Section 2). Next we turn to a supply-demand analysis of retail margins to determine the factors influencing the impact of efficiency standards on retail price (Section 3). Following, we evaluate retail margins in selected industries to determine how well a simple supply-demand analysis explains observed market trends (Section 4). In Section 5 we apply the lessons learned from this analysis to retail margins in the appliance sector. In the concluding section (Section 6) we summarize our findings and suggest implications with regards to the consumer benefits of appliance standards. The paper concludes with general observations about retail margins, manufacturing costs and appliance efficiency standards.

The original manufacturing price (or cost of goods sold) of more efficient appliances is usually expected to be higher than the manufacturing price of baseline, less efficient appliances[1]. This assumption has sparked debate about the impact of standards on the retail price of appliances. In order to better understand this issue, we investigate the relationship between the retail price of goods

[1] In this paper, we use the terms original price and cost of goods sold interchangeably, representing the price charged by the manufacturer, or in the case of natural resources, the harvester, of the good; this is equivalent to the materials cost faced by the retailer of the final product.

and the cost of goods sold (CGS). This price-cost differential is generally termed the margin or retail margin.

Two definitions of margins are used in this study: (1) the percent margin, the ratio of final retail price to original manufacturing price, and (2) the dollar margin, the difference between the final price and the original price. Some appliance retail analysts and manufacturers contend that percent margins are more or less fixed, implying for example that a ten percent increase in the manufacturing price will cause the retail appliance price to rise ten percent. For example, The American Home Appliance Manufacturers (AHAM) has issued consultant reports and papers supporting this position. On the other hand, economic theory suggests that dollar margins for competitive firms are fixed, assuming inelastic demand and retail costs that are invariant to manufacturing price [1]. This theory implies for example that a ten percent rise in manufacturing cost will cause a less than ten percent increase in the retail price for such firms.

3 Factors Influencing the Impact of Efficiency Standards on Retail Price

In this section we evaluate the impact of efficiency standards on retail prices given different assumptions about market competition and retail cost curves. We begin by examining retail prices assuming competitive firms with horizontal supply (Section 3.1) and rising supply curves (Section 3.2). In the appendix we include a discussion of final retail prices under various demand conditions (Appendix A.1) and the influence of market power (Appendix A.2).

3.1 Retail Margins Assuming Perfect Competition with Constant Costs

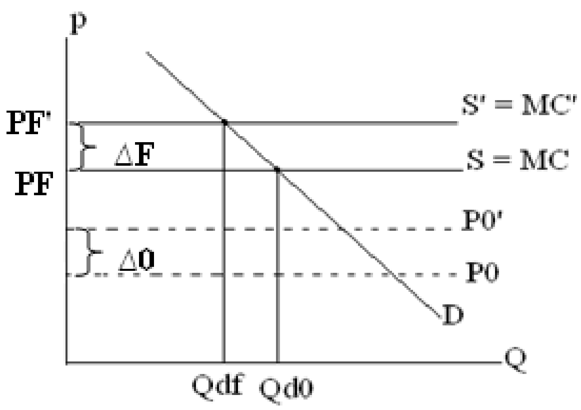
Under perfect competition, products are priced at marginal cost [1]. Assuming constant costs (perfectly elastic supply), marginal cost equals average unit manufacturing price plus average unit retail cost. This implies that the final retail price (P_F) is set equal to unit costs faced by the retailer. As represented by the following equation, the change in final price (Δ_F) due to an efficiency standard equals the change in original manufacturing price (Δ_0) added to the change in unit retail cost (MC_{RTL}):

$$\Delta_F = \Delta_0 + MC_{RTL}$$

This change in retail price due to an efficiency standard assuming perfect competition and constant costs is illustrated in Figure 3-1.

This model of margin determination in the case of perfect competition and constant costs implies that the increase in final price will equal those changes in costs associated with the increasing cost of a good. Some retail costs, such as insurance, inventories and equipment financing cost, are likely to increase if original price goes up and will contribute to the increase in the final price. Other costs, including labor and occupancy costs, are not likely to increase with original price and will not contribute to the increase in final price or be included in the retail margin.

Figure 3-1 Relationship between Consumer Price and Marginal Cost assuming Perfect Competition and Constant Costs



3.2 Impact of Rising Costs on Margins

As shown in Figure 3-2**Error! Not a valid bookmark self-reference.**, under perfect competition with rising costs, products are priced at marginal cost. In this case, the upward shift in marginal cost (the supply curve) caused by standards is shared between the producers and the consumers such that Δ_F could be less than the shift in marginal. Thus, in this case, the final price to the consumer rises less than the upward shift in marginal cost. The fraction of the shift in marginal cost which is paid by the consumers, called the pass-through fraction, is dependent on the elasticity of supply and demand curves [1]:

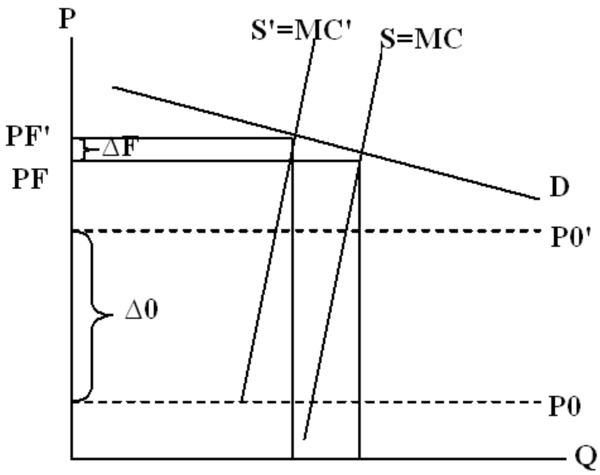
$$Pass - through\ Fraction = \frac{E_s}{(E_s - E_d)}$$

where, E_s = supply elasticity

E_d = demand elasticity

Note that under normal market conditions with upward sloping supply curves and downward sloping demand curves, the pass-through fraction must be a positive number less than or equal to 1.

Figure 3-2 Customer Price as a function of Marginal Cost with upward shift in Supply Curve



As we can see, the fraction of the upwards shift in marginal cost that is passed through to the consumers varies inversely with the market wide elasticity of demand, and varies directly with the elasticity of supply.[2] Intuitively, if the demand is relatively more elastic (the slope of the demand curve is flatter), this means consumers are more sensitive to the price change. Therefore, in this market any increase in the retail price will lead to firms losing sales and market share. In this case, a portion of the incremental costs will be transferred to the producers, resulting in a smaller margin for retail firms and a smaller markup for consumers.

4 Empirical Studies of Retail Margins

In this section, the supply-demand models of Section 3 are used to explain the behavior of original prices, final retail prices, and retail margins in four industries,—oil and gas, lumber, real estate, and electronics and appliance stores. Retail pricing behavior in these industries provides some perspective on a range of retail pricing practices. In these examples, original price or cost of goods sold is defined as the price at the initial stage of production, the final retail price is the price of a finished product sold to consumers, and the retail margin is the difference between the final price and the CGS.

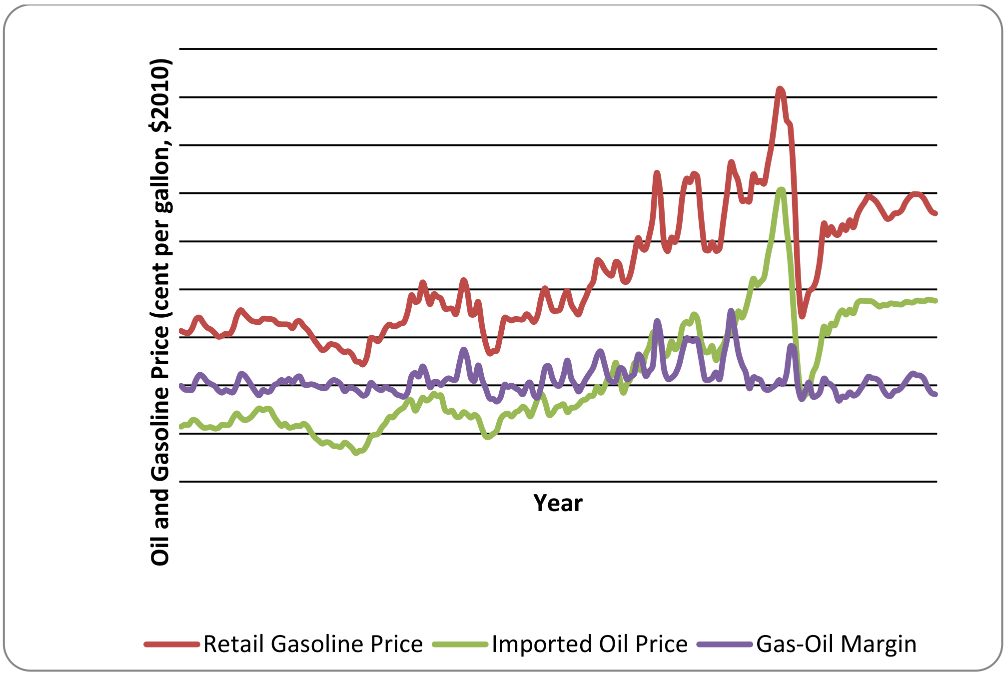
[2] E_d is defined as negative. (Price increases result in lower quantity demanded.)

4.1 Oil and Gasoline Industry

The U.S. gasoline retail market has few barriers to entry, the demand for gasoline is relatively inelastic, and gasoline inventory is a minor part of total cost [2] [3]. Since the U.S. oil price is largely set at the international price, the supply of gas is represented as nearly horizontal. With relatively few substitutes, the demand for gasoline is steeply declining. In this case, a rise in the price of the primary product (oil) results in a nearly identical upward shift in the price of the final product (gasoline), as illustrated above in Figure 3-1.

The empirical data presented in Figure 4-1 strongly supports this interpretation. Between 1995 and 2008, rising demand for oil in Asia and other regions led to a $2.50 per gallon increase in the price of oil, from $0.50 to $3.00 per gallon. During this time, the price of refined automobile gasoline also rose by $2.50 per gallon. Thus, gasoline retail margins remained fixed at $1.00 per gallon throughout the period despite a 500% rise in the CGS. In short, the oil and gas market illustrates a case where increasing CGS lead to nearly constant dollar margins.

Figure 4-1 Oil and Gasoline Prices



Source: U.S. Energy Information Agency, Oil price: Spot price in Cushing Oklahoma for a 42 gallon barrel of oil, Retail gas price: US average retail price of gasoline, all grades and formulations.

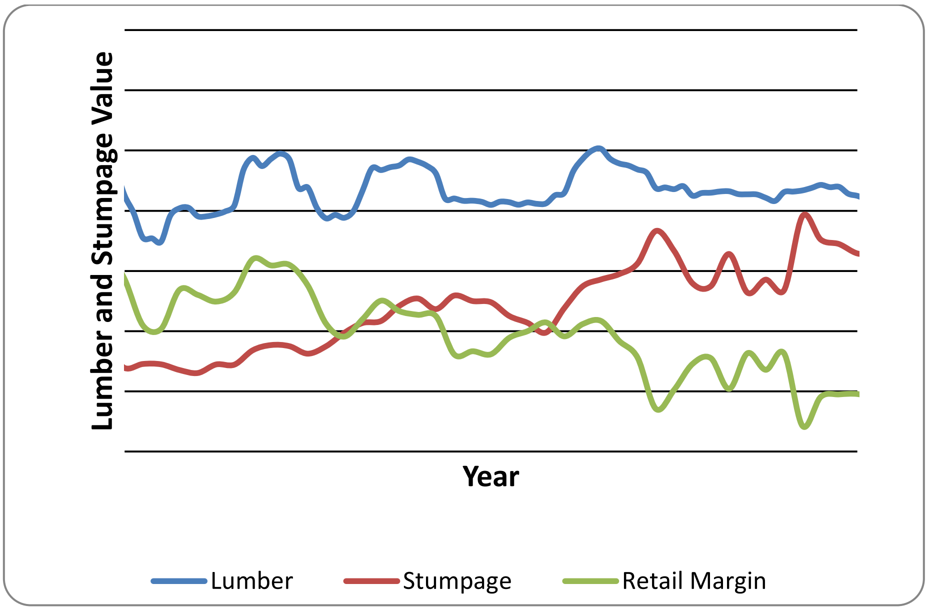
4.2 Midwestern Red Oak Hardwood Market

In stark contrast to oil and gas, the Midwestern red oak lumber market is characterized by an inelastic supply and elastic demand. The supply of red oak trees is inelastic because of the time it takes for oak trees to reach maturity. With many close substitutes, the demand for red oak lumber is relatively elastic. In addition, the lumber market in the region is served by a mix of new, low cost lumber mills and older, higher cost mills [4].

These factors suggest that the demand for red oak lumber is a nearly horizontal line and the supply as a nearly vertical line (Figure 3-2). In such a market, a rise in the original price (stumpage price) results in a relatively small final price increase perceived by consumers, and declining markups and retail margins.

This interpretation of the market for Midwestern hardwood is supported by red oak price data collected between 1980 and 2000. Tight lumber markets between 1980 and 1995 caused a sustained rise in the stumpage price during this period, while retail prices remained remarkably stable, apart from three short lived jumps in the retail price (Figure 4-2). As a consequence, the nearly 300% rise in the price of the raw product was offset by a similar decline in retail margins so that consumers experienced little change in retail prices.

Figure 4-2 Hardwood Lumber and Raw Timber Prices



Source: Dr. William Luppold. Forest Sciences Laboratory, Princeton West Virginia. May, 2010

4.3 Real Estate Market

Our third market study--the sale of residential homes—illustrates a market where retail costs are strongly and positively correlated with the original price. The retail margin in this market is represented by the agents' commission, and the original price (CGS) in this market is represented by the housing price less the agent's commission**.**

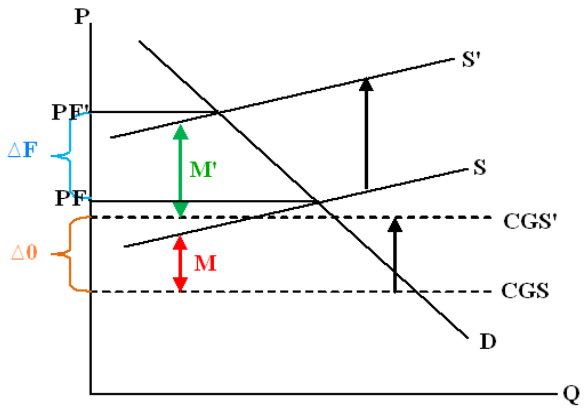
In the residential housing market, demand is generally considered to be slightly inelastic [5] [6], and long term supply to be very elastic [7]. Ordinarily, this would suggest that real estate broker margins would be relatively constant in dollar terms as was the case for oil and gas (Figure 3-1). However, in this market, the value of services supplied at the retail level by real estate brokers is also positively associated with the price of homes. For example, brokerage services include listing and advertising homes, preparing papers, screening buyers and, perhaps most important, negotiating the price and terms of house sales. The value of performing these tasks well is likely to be enhanced, and the costs of incompetence likely to be greater, when handling high priced as compared to low priced homes. As a result, the educational level of real estate brokers in some regions has risen sharply between 1985 and 2005 in line with the average price of homes.[3]

These factors suggest that the market for real estate is characterized by a steeply declining demand curve and a relatively flat supply curve as with the oil and gas market. However, in contrast to oil and gas markets however, a given rise in the price of the original good in this case leads to a disproportionately large rise in the supply curve (Figure 4-3). Therefore, the final retail house price for consumers is a function of the initial values of houses. The increase in CGS is expected to lead to a greater increase in final transaction house price. When the initial house price (CGS) goes up, the final price actually bumps up higher than the increase in CGS due to the higher margins (commissions) charged by brokers. As shown, dollar margin after the initial price increase is greater than dollar margin before the increase in absolute terms, but smaller as a percent of the final transaction price.

Figure 4-3 Supply and Demand Curves for the Real Estate Market

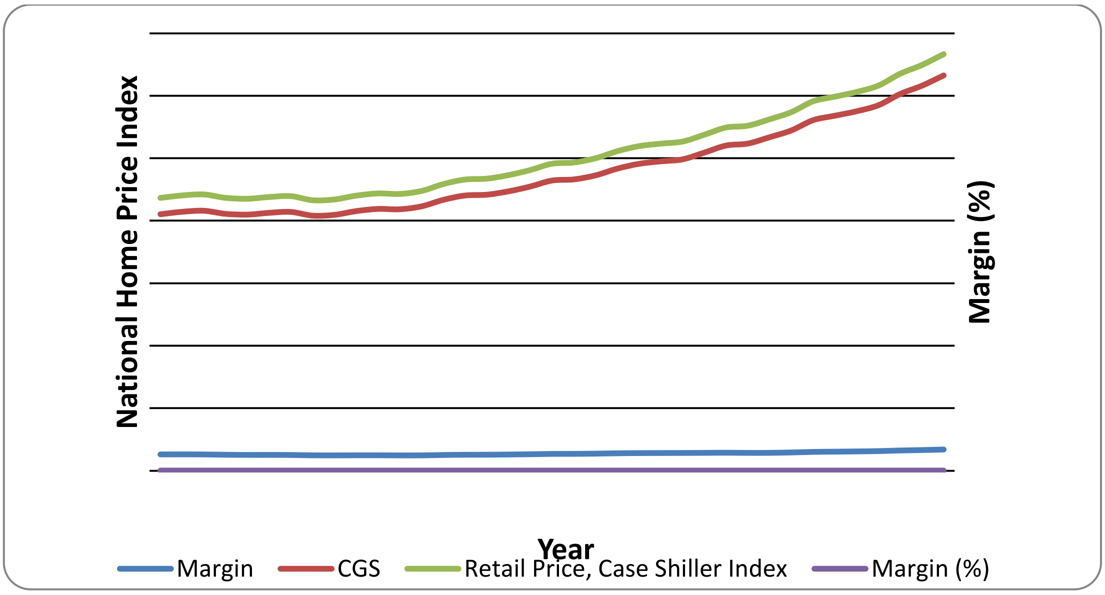
---

[3] Eugene Millstein and Associates. Personal communication, Berkeley California. 2010.



This interpretation of the U.S. real estate market is borne out by the historical home price and brokerage fee data between 1995 and 2005. As shown in Figure 4-4, there was a steady increase in housing prices between 1995 and 2004, with average housing prices increasing 53% in real terms during this period. At the same time, agent commissions (retail margin) as a percent of CGS declined from 6.4% in 1995 to 5.4% in 2005 [8]. In short, the real estate market illustrates a case where increasing CGS leads to increasing dollar margins and decreasing percent margins at the retail level.

Figure 4-4 Residential Housing and Brokerage Commissions



Source: Retail price:Standard and Poors, Case-Shiller home price index, CPI adjusted. http://www2.standardandpoors.com/spf/pdf/index/csnational_value_052619.xls

5 Retail price setting in appliance and electronics stores

Retail pricing of appliances is likely to be more complicated than pricing of commodities, such as lumber and oil and gas. This is because appliance retail stores typically sell a wide variety of goods, including consumer electronic goods (e.g., televisions), and business appliances (e.g., computers), along with major appliances (e.g., refrigerators). In such an environment, retail pricing strategies may vary, with prices and margins set low for some goods, to maximize market share, and high for others, to attract elite or status conscious clientele. Detailed appliance price and retail margin data is difficult to acquire, so to evaluate the impact of higher original product prices on retail prices and margins in this section we apply the lessons learned from our empirical analysis to evaluate the data that is publically available on appliances.

Three principle lessons are drawn from this review of the impact of raising the original product price on the retail price:

- The impact is constant (one to one) in cases when the supply curve is elastic and the demand curve is inelastic (e.g., oil and gas)
- The impact is diminished (less than one to one), in cases where the supply curve of the product is inelastic and the demand curve is elastic (e.g. timber).
- The maximum impact is increased in both the above cases, when retail costs are correlated with original product prices (e.g., real estate),

Of these, the first and third lessons are most applicable. The supply curve for manufactured appliance goods is likely to be very price elastic, given potential economies of scale in appliance manufacturing and the ease of entry, and competitive nature of appliance retailing in the United States [9]. The demand curve for appliances is also likely to be at least somewhat inelastic, particularly in the short run [10]. This suggests that a rise in the primary appliance price (CGS) will generally be carried through to the retail price on at least a one to one basis, as was the case for the oil and gas markets.

In addition, there is a possibility that some appliance store retail costs are positively correlated with the primary price (CGS). A breakdown of these cost categories indicates a mix of cost categories for household appliance stores, including some retail labor related cost categories and other inventory and financial related cost categories. Table 5.1 is an example of cost breakdown for the household appliance store sector.

Table 5.1 Household Appliance Store Cost Categories

Kind of Business and Item	Amount ($1,000,000)	% of Sales
Sales (Revenue)	10343	100.0%
Cost of Goods Sold (CGS)	7151	69.1%
Gross Margin (GM)	3193	30.9%
Payroll and Occupancy Expenses		
Payroll	1366	
Fringe Benefits	208	
Contract Labor	69	
Taxes and License Fees	53	
Lease and Rental Payments	238	
Telephone and Communications	58	
Utilities	70	
Repair and Maintenance	36	
Subtotal:	2098	20.3%
Total Other Operating and Profit		
Depreciation and Amortization	94	
Office Supplies	37	
Packaging and Other Materials	0	
Advertising Services	274	
Legal Services	8	
Accounting, Auditing, and Bookkeeping	19	
Computer Related Services	10	

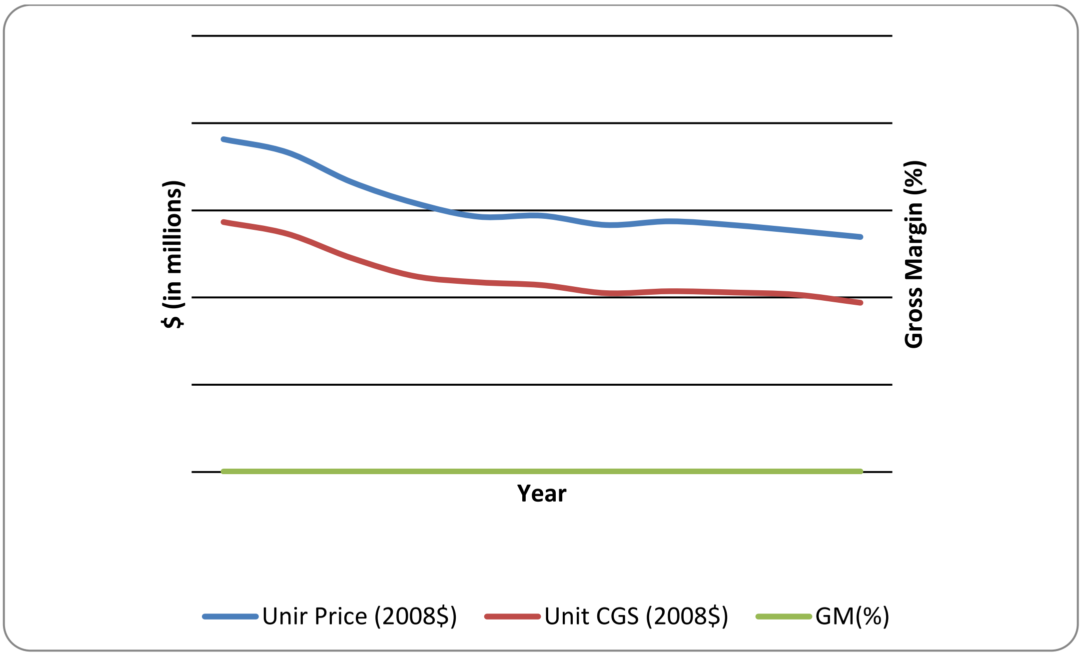
Other Operating Expenses	389	
Net Profit Before Taxes	263	
Subtotal:	1094	10.6%

Source: U.S. Census, 1997 Business Expenses Survey

Of these, discussions with appliance retail consultants suggest that financial costs of retail firms may rise in proportion to CGS but labor related costs, roughly two thirds of all costs, are almost certainly unrelated to CGS.[4] For example, little if any more sales staff are needed to sell high priced goods than to sell lower priced goods. We conclude from this that retail margins in this sector are likely to behave similarly to real estate brokerage margins—with dollar margins rising and percent margins decreasing with CGS.

Aggregate data obtained from the U.S. Census and Appliance Magazine tends to support this finding. Data from the U.S. Census's Historical Annual Retail Trade Report for Electronics and Appliance Stores (NAICS 443) provide information about revenue and gross margin for electronic and appliance stores selling major appliances, electric housewares, consumer electronics, comfort conditioning, floor care appliances, personal care appliance, and business appliances between 1997 and 2007. Data from Appliance Magazine provide information about sales volume for these same seven appliance categories. The proportion of total sales within each appliance category has remained relatively stable since 1997 (See Appendix B). Thus, the data allow us to track changes in unit sales and thus unit price and margin over this period (Figure 5-1).

Figure 5-1 Unit Price and Gross Margin for Electronics and Appliance Stores



In contrast to commodity prices, the unit price and CGS of appliances has steadily declined between 1997 and 2007. In response, and as predicted, the dollar retail margin decreased slightly for appliance stores, and the percent margin increased. In other words, the retail margin of U.S. appliances is analogous to the real estate market except that in this case the CGS has been declining instead of increasing.

---

[4] Personal communication with a retail consultant familiar with pricing practices of electronic goods.

6 Conclusion

There is little empirical evidence to support the general proposition that a higher cost of goods sold generally translates into higher retail percent margins. Price data from timber, oil and gas and real estate markets suggest that margins may change in a number of ways--declining, remaining constant or even increasing, but in no case do margins increase in proportion to CGS as a general rule. All three markets experienced sharply rising cost of goods sold. In the oil and gas industry, rising oil prices were simply passed on to customers with little impact on dollar margins. In the hardwood industry, higher stumpage prices led to falling dollar margins. In the residential housing sector, higher home prices were accompanied by declining real estate margins (brokerage fees) in percent terms, but rising in dollar value.

Three principle lessons are drawn from this review of the impact of raising the original product price on the retail price:

- The impact is constant (one to one) in cases when the supply curve is elastic and the demand curve is inelastic (e.g., oil and gas)
- The impact is diminished (less than one to one), in cases where the supply curve of the product is inelastic and the demand curve is elastic (e.g. timber).
- The maximum impact is increased in both the above cases, when retail costs are correlated with original product prices (e.g., real estate),

Current understanding of the relevant demand and supply curves suggests that two of these--the first and third—have some applicability to appliance markets. Appliance demand is inelastic and supply is very elastic so that, as with oil and gas markets, any increase in the cost of goods sold (that might follow standards) would likely be passed on fully to consumers [9] [10]. In addition, financing costs at the retail level may increase with cost of goods sold. Together, these market characteristics suggest that appliance standards have the potential to increase retail dollar margins but not retail percent margins. This finding is supported with data collected from the U.S. Census and Appliance Magazine, indicating that appliance retail percent margins are inversely correlated with retail price levels.

References

[1] Pindyck Robert and Rubinfeld Daniel. Microeconomics Fourth Edition. 1998. Prentice-Hall, Inc. New Jersey.

[2] Hughes J., Knittel C., and Sperling D. *Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand*. NBER Working Paper No. 12530. September 2006.

[3] Krichene N. *World Crude Oil and Natural Gas: A Demand and Supply Model.* Energy Economics. 2002.

[4] Luppold W., Prestemon J. and Baumgra J. *An Examination of the Relationships Between Hardwood Lumber and Stumpage Prices in Ohio.* The Society of Wood Science and Technology. 1998

[5] Polinsky A. M. and Ellwood, D.T. *An Empirical Reconciliation of Micro and Group Estimates of the Demand for Housing*. Review of Economics and Statistics 1979, vol. 61, pp. 199-205

[6] Maisel S.J., Burnham J.B., and Austin J.S. *The Demand for Housing*. Review of Economics and Statistics 1971, Vol. 53, pp. 410-413.

[7] Fallis, G. *Housing Economics*, Butterworth, Toronto, 1985.

[8] Weicher. J. *The Price of Real Estate Brokerage Services: A Review of the Evidence, Such As It Is*. Real Estate Law Journal. Summer 2006

[9] http://www1.eere.energy.gov/buildings/appliance_standards/residential/residential_clothes_dryers_room_ac_direct_final_rule_tsd.html

[10] Dale L. and Fujita K. *An Analysis of the Price Elasticity of Demand of Household Appliances*. LBNL 326E, 2008. Can be downloaded at: http://www.osti.gov/bridge/servlets/purl/929429-Vm1S9X/929429.pdf

[11] Hausman, Jerry A. *Individual discount rates and the purchase and utilization of energy-using durables*. The Bell Journal of Economics Literature. 1979.

[12] Fredrick Shane. Loewenstein Georage. O'Donoghue Ted. *Time Discounting and Time Preference, a Critical Review*. Journal of Economics Literature. 2002.

[13] Bhuyan, Sanjib and R. A. Lopez. Welfare losses under alternative oligopoly regimes: The U.S. food and tobacco manufacturing industries. Journal of Agricultural and Applied Economics. 1995.

[14] Bachmeier L., and Griffin J. *New Ecidence on Asymmetric Gasoline Price Responses*. The Review of Economics and Statistics. August 2003.

[15] Lewis Matthew. *Asymmetric Price Adjustment and Consumer Search: An Examination of the Retail Gasoline Market*. Working Paper for the Center of the Study of Energy Markets (CSEM). November 2003.

Appendix A: Additional Price Impacts

A.1 Impact of Demand Shift on Margins

It is likely that efficiency standards would create no shift or a small upward shift in the demand curve as the quality of the good increases due to the efficiency standard [11] [12].[5] While the size of this shift is hard to predict, we can gauge its effects by examining the quantity of goods demanded by consumers. If there is no shift in the demand curve, the quantity of goods demanded falls depending on the elasticity of demand and supply.

We could define a small upward demand curve shift as one that leaves the quantity of goods demanded at or below pre-standard levels, but greater than the quantity demanded assuming only a shift in the supply curve. In this case we would find the pass through fraction to be larger than seen under just the supply curve shift, but it would still range from zero to one. If there was a large demand curve shift, the quantity demanded would increase to a level greater than that demanded before the standard was implemented. In this case the pass through fraction would be greater than one, and would depend on the size of the increase in demand.

We can summarize the effects of elasticity and demand shift based on one measurement. If, after the standard is implemented, the quantity of good demanded falls the pass through fraction will range from zero to one. If after the standard is implemented, the quantity of good demanded increases, the pass through fraction will be greater than one. If after the standard is implemented, the quantity of good demanded stays the same then the pass through fraction will equal one.

In a situation with rising marginal costs, where the market demand is extremely elastic, we might see very little change in price due to a given shift in marginal cost. In this situation, provided most of the cost increases seen by the firm came in the form of an increase in cost of good, we might find an incremental margin of less than one. In a situation where demand shifted outwards due to increased appreciation of the benefits of efficient appliances, we might see a larger incremental margin. However, this effect is due to changing consumer preferences as opposed to increased costs to manufacturers, wholesalers, and retailers.

A.2 Impact of Market Power on Margins

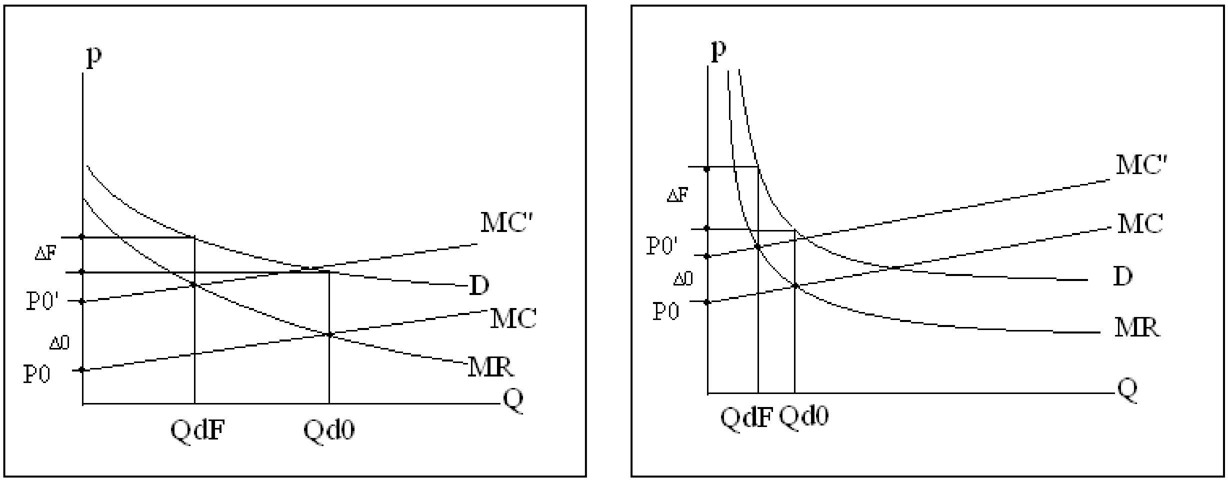
Unlike a firm under perfect competition, a firm with market power is not a "price taker." A firm may choose its quantity that it sells and charge the maximum price given the demand. The profit maximization rule--marginal revenue equal to marginal cost--applies when firms with market power maximize their profit. Under market power, price will be greater than marginal cost. Here, we define an "economic margin", m_e, as:

$$m_e = \frac{\Delta_F}{MC_{RTL}}$$

Error! Reference source not found. shows such firms facing a highly elastic residual demand. This is a case where a firm has very limited market power. Such firms will see an economic margin of less than one. In Figure A-2we see an example of a firm that faces an inelastic residual demand. In this case, the economic margin is greater than.

Figure A-1 Elastic Residual Demand **Figure A-2 Inelastic Residual Demand**

[5] The sources cited support high implicit discount rates and thus low demand shift (due to a low consumer value for time discounted energy savings).



The economic margin is estimated as a function of the elasticity of market demand in the following equation [13]:

$$L = \frac{(P_F' - MC_W)}{P_F'} = \frac{\big(H + \alpha(1-H)\big)}{E_d}$$

In this equation, P_F', MC_w, H, α and E_d represent the price, marginal cost, Herfindhal-Hirschman index, collusion parameter, and absolute value of the demand elasticity, respectively. The collusion parameter (α) represents the degree of industry wide collusion, where Cournot and perfectly collusive behavior are represented by $\alpha = 0$ and $\alpha = 1$, respectively. The Herfindahl-Hirchman index (H) measures industry concentration (H approaches 0 under perfect competition and exceeds 1000 for moderately concentrated industries). The market demand elasticity (E_d) indicates the responsiveness of production to changes in the price ($E_d < 0$). The other variables in the equation are defined above.

Solving for P_F' gives,

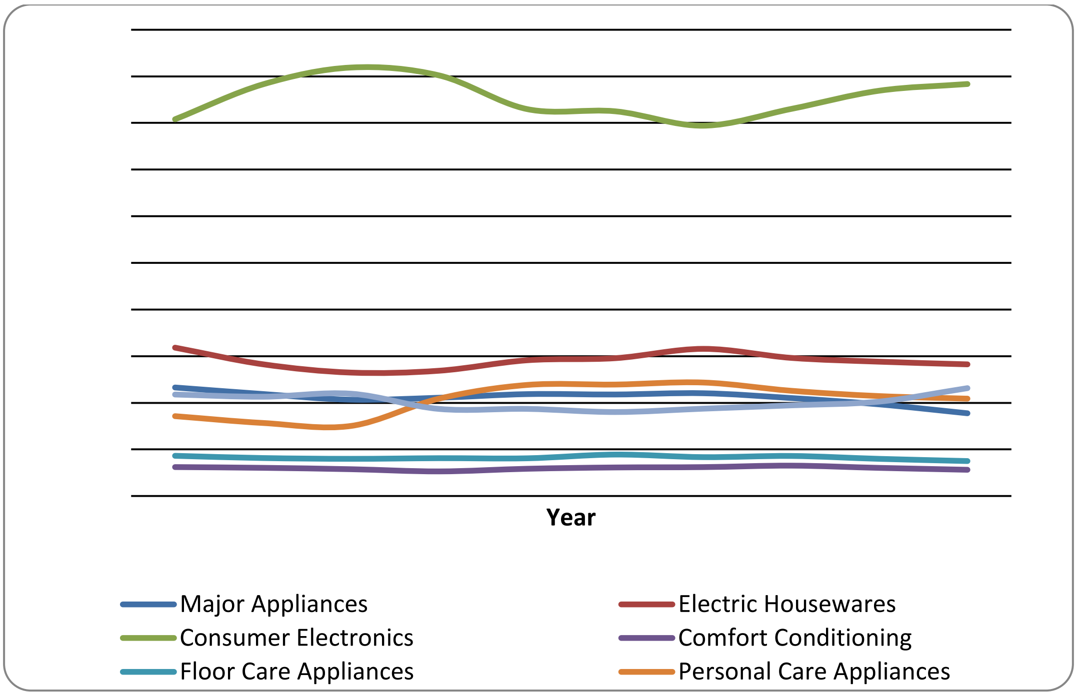
$$P_F' = MC_W \times \left[\frac{E_d}{\Big(E_d - \big(H + \alpha(1-H)\big)\Big)}\right]$$

This expression demonstrates how marginal cost, demand elasticity and other variables interact to determine the consumer price. When firms have market power as described by this equation, our method for calculating margins needs to be adjusted. In the equation, price equals marginal cost times a multiplier (E_d / (E_d - (H + α(1-H))). Since the multiplier is itself a function of the price elasticity, the economic margin varies according to price elasticity value. Depending upon the size and potential changes in elasticity value, the multiplier may be larger or smaller than one as illustrated above (Figure 3.3 and Figure 3.4).[6]

Appendix B: Sales Breakdown of Various Appliances from Appliance Magazine[7]

[6] Here we need to adjust the method used to calculate incremental margins. Unlike the case of perfect competition, firm profits are positive and firm income exceeds the opportunity cost of capital. As long as the firm makes as much or equal to the opportunity cost of capital, it will continue to produce. Thus, the opportunity cost of capital (the profit section of the survey) would not be included in margin calculations using the Lerner index.

[7] Appliance Magazine, Statistical Review, 48th and 55th Annual Report


Year
Major Appliances
Electric Housewares
Consumer Electronics
Comfort Conditioning
Floor Care Appliances
Personal Care Appliances

Standards and labeling in India: Roadmap for 2030

Tanmay Tathagat and Prasoon Kumar Yadav, EDS
Yamina SAHEB[1], IFRI, Michael McNeil, LBNL, Bodhisatya Datta, CLASP

Abstract

Currently the Indian mandatory standard and labeling (S&L) program covers frost-free refrigerators, room air conditioners, fluorescent lamps and transformers. Direct cool refrigerators, ceiling fans, induction motors, color TVs, washing machines and gas stoves are regulated under voluntary labeling scheme.

To develop a long term appliances standard and labeling strategy (2010-2030), a preliminary product prioritization analysis was conducted for the Bureau of Energy Efficiency (BEE). The aim of this analysis is to select the next set of products to be regulated based on their energy savings and CO_2 emission reduction potential. Products considered in the study have been chosen broadly by BEE on the basis of their penetration into the Indian residential, commercial and industrial sectors. However, the paper focuses only on products used in residential and commercial sectors, and electric motors. The analysis includes new products that are yet to be labeled, as well as products already being labeled so as to analyze the impact of more stringent energy requirements.

The paper describes the methodology and data required to assess the impact of standard and labeling programs in terms of energy savings, reduction of peak electricity demand and CO_2 emissions for various products used in residential and commercial sectors. The analysis showed that although room air conditioners are already regulated and the energy efficiency is being improved, their savings potential is still high. In fact, when considering the rapid penetration of room air conditioners into Indian buildings and the extreme climate conditions in India, increasing stringency of the existing scheme will result in over 113 TWh annual energy savings which represent 93 Mt CO_2 eq. annual GHG abatement and 79 GW of peak demand reduction by 2030.

The two other products to consider are motors (86 TWh annual energy savings which represent 71 Mt CO_2 eq.) and TVs (62 TWh annual energy savings which represent 51 Mt CO_2 eq. annual abatement) Both are currently regulated under voluntary labeling scheme, BEE is likely to make these programs mandatory and introduce a schedule to phase out less efficient products from the market.

At this stage, the analysis gives a big picture for the next S&L steps in India. However, several assumptions and data need to be further refined in order to define BEE's 2030 strategy.

Introduction

In 2006, the Bureau of Energy Efficiency, BEE, implemented a voluntary Star Rating comparative energy labeling program for frost-free domestic refrigerators, room air conditioners, tubular fluorescent lamps and distribution transformers. By 2010, the program became mandatory for the products listed above with the exception of direct cool refrigerators and a schedule to phase out the less efficient room air-conditioners [Table 1] and frost-free refrigerators [Table 2] has been introduced. In addition, a voluntary program for a new set of products, which includes, pumps (moonset, openwell, submersible), industrial motors (used for a wide variety of applications including AHUs, all kinds of water pumps, industrial fans), ceiling fans, domestic gas stoves, water heaters, TVs and washing machines, has been implemented.

In order to develop a long term appliances standard and labeling strategy (2010-2030), BEE, with support from ClimateWorks Foundation, CLASP and LBNL, commissioned a preliminary product prioritization analysis. The aim of the analysis was to select the next set of products to be regulated under standard and labeling (S&L) programs based on their energy savings potential and CO_2 emissions reduction.

[1] Corresponding author: saheb@ifri.org

	Jan 2010 to Dec 2011		Jan 2012 to Dec 2013		Jan 2014 to Dec 2015	
Star Rating	Min EER [W/W]	Max EER [W/W]	Min EER [W/W]	Max EER [W/W]	Min EER [W/W]	Max EER [W/W]
1 Star	2.30	2.49	2.50	2.69	2.70	2.89
2 Star	2.50	2.69	2.70	2.89	2.90	3.09
3 Star	2.70	2.89	2.90	3.09	3.10	3.29
4Star	2.90	3.09	3.10	3.29	3.30	3.49
5 Star	3.10		3.30		3.50	

Table 1: Energy classes and MEPS thresholds & schedule for RACs [1]

	Jan 2010 to Dec 2011		Jan 2012 to Dec 2013		Jan 2014 to Dec 2015	
Star Rating	Constant Multiplier k_{nf} [kWh/l/yr]	Constant Fixed Allowance c_{nf} [kWh/yr]	Constant Multiplier k_{nf} [kWh/l/yr]	Constant Fixed Allowance c_{nf} [kWh/yr]	Constant Multiplier k_{nf} [kWh/l/yr]	Constant Fixed Allowance c_{nf} [kWh/yr]
1 Star	0.8716	759	0.6973	607	0.4463	389
2 Star	0.6973	607	0.5578	486	0.3570	311
3 Star	0.5578	486	0.4463	389	0.2856	249
4Star	0.4463	389	0.3570	311	0.2285	199
5 Star	0.3570	311	0.2856	249	0.1828	159

Table 2: Energy classes and MEPS thresholds & schedule for frost-free refrigerators [2]

Products considered in the study have been chosen broadly by BEE on the basis of their penetration into the Indian residential, commercial and industrial sectors. However, the paper focuses only on products used in residential and commercial sectors as well as electric motors. The analysis includes new products that are yet to be labeled, as well as products already being labeled so as to analyze the impact of more stringent energy requirements.

The paper describes the methodology and data required to assess the impact of standard and labeling programs in terms of energy savings, reduction of peak electricity demand and CO_2 emissions. It reports the main findings, draws a number of conclusions and makes recommendations for actions by BEE.

Main assumptions

Products included in the analysis have been chosen broadly by BEE on the basis of their penetration into the Indian residential and commercial sectors. Both products already regulated under S&L programs and those considered for regulation in the near future have been included in the analysis. The driver was to analyze the impact of more stringent requirements for the regulated products as well as the impact of regulating new products.

For the purpose of the analysis, we assumed 2007 as a baseline and an effective implementation of mandatory S&L programs for all the products included in our list by 2014 considering funds available to support BEE.

2007 annual sales, expected market growth rates and average power consumption are based on reports & news published by the industry when available and for some products on experts' interviews. Mean life time and usage of the appliances are based on our knowledge of the use of the appliances in India. Table 3 summarizes all the assumptions considered in the analysis [3].

In addition to the criteria described above, we considered additional "implementability" variables that take into account the specific situation of the market and implementation issues in India, such as the existence of manufacturers' organizations, market fragmentation in organized and unorganized segments, and technical variables such as suitability of Indian and international test procedures, However, since these parameters are largely qualitative, care must be taken in their combination with energy-related variables and its interpretation. For clarity of presentation, therefore, they are not presented in this paper.

	Product	2007 annual sales (No of units)	Expectd growth (2007-2014)	Expecte dgrowth (2014-2020)	Expecte growth (2020-2030)	No units sold cumulatively (2014-2030)	Post 2014 stock surviving in 2030	Average power consumption (W /h)	Mean lifetime	Usage per day (hrs/day	Days of usage /year	UEC (KWh/yr	Energy savings potential %
	Water purifiers	500.000	15%	15%	15%	86.550.521	60.117.439	19	7	2	300	11	15%
	Desert coolers	2.930.000	10%	10%	10%	231.499.756	143.813.965	250	7	10	150	375	25%
	Table fans/Pedestal	9.000.000	4%	4%	4%	280.658.787	191.045.272	80	10	6	250	120	30%
	Exhaust fans (ventilation)	2.700.000	12%	12%	12%	291.778.819	229.746.705	150	10	4	200	120	15%
	Washing machines	2.365.000	7.5%	7.5%	7,5%	126.569.279	73.381.102	800	7	2	300	190	20%
	Mixers and Grinders	1.873.000	10%	10%	10%	147.986.022	91.932.955	500	7	1	200	50	10%
	Microwave ovens	616.137	12%	12%	12%	66.583.602	43.422.685	1.400	7	1	250	155	15%
	Toasters	551.000	14%	14%	14%	81.508.399	45.815.012	1.400	5	0	200	70	10%
Home Appliances and Equipment	Electric iron.	1.380.000	8%	8%	8%	79.821.899	37.141.790	1.200	5	1	200	120	1%
	Vaccum Cleaner	153.000	5%	5%	5%	5.563.079	2.979.258	1.200	7	1	100	60	15%
	Electric heaters	337.000	10%	10%	10%	26.626.422	16.541.060	900	7	4	50	180	10%
	Immersion heaters	822.000	8%	8%	8%	47.546.088	22.123.588	500	5	2	100	100	1%
	RACs	2.253.000	15%	15%	15%	389.996.648	319.294.811	1.641	10	8	180	2.363	15%
	Refrigerators	5.150.000	10%	10%	10%	406.902.302	310.832.133	300	10	10	365	400	15%
	Ceiling fans	10.000.000	11%	11%	11%	923.908.766	839.764.949	65	15	12	250	195	20%
	Geysers	780.000	15%	15%	15%	135.018.813	93.783.205	2.600	7	2	150	780	5%
	Music systems	1.800.000	5%	5%	5%	65.447.983	35.050.095	40	7	3	200	24	20%
	VCD/DVD players	3.000.000	20%	15%	10%	1.138.704.996	353.425.896	25	7	3	100	8	10%
	Cordless phones	153.000	2%	2%	2%	3.517.100	1.686.824	3	7	24	300	19	72%
	Inverters	2.000.000	8%	8%	8%	115.683.912	68.056.567	14	7	24	350	117	10%
Consumer Electronics	Voltage stabilizer	966.000	10%	10%	10%	76.323.810	47.414.434	14	7	24	350	276	10%
	UPS	1.937.817	13%	13%	13%	244.991.998	163.368.420	140	7	20	350	980	10%
	Cell phone chargers	40.000.000	18%	10%	5%	11.094.118.304	1.203.743.136	2	3	4	350	3	50%
	TVs	13.500.000	15%	15%	10%	2.336.864.068	948.537.956	120	5	6	365	263	25%
	Set Top boxes	4.000.000	25%	15%	5%	692.404.168	351.262.273	9,25	5	24	365	81	41%
	Computer monitors	7.519.758	15%	10%	5%	1.301.677.946	365.791.049	42	7	10	200	84	25%
	Personal computers	7.447.277	15%	10%	5%	1.289.131.409	279.417.294	98	5	10	200	196	10%
	Laptops	2.567.372	30%	20%	10%	4.591.538.736	384.451.978	60	3	8	200	96	10%
	Laptop chargers	3.080.847	30%	25%	15%	5.509.847.557	666.162.581	4	2	8	200	6	53%
	Computer servers	293.233	20%	20%	20%	111.301.961	71.717.306	350	5	24	350	2.940	10%
Office Equipment	Printers	2.503.070	13%	13%	13%	316.455.150	173.066.098	30	5	10	200	59	50%
	Photocopiers	300.000	20%	20%	20%	113.870.500	85.951.583	25	7	10	200	49	40%
	Fax machines	214.208	20%	20%	20%	81.306.573	61.371.722	15	7	10	200	30	59%
	Scanners	75.000	20%	20%	20%	28.467.625	18.343.085	19	5	2,25	200	9	47%
	Routers/modems/hubs	511.826	5%	5%	5%	18.609.988	5.146.677	15	3	24	350	126	10%
	Electric hard disk drive	1.151.685	30%	30%	30%	1.299.354.337	82.874.121	23	5	1	200	5	1%
	Chillers	7.182	15%	15%	15%	1.243.212	1.017.832	98.000	10	10	200	196.000	30%
	Central AC and HP	86.953	10%	10%	10%	6.870.170	5.248.114	8.400	10	10	200	16.800	20%
	Motors	2.000.000	10%	10%	5%	107.035.331	92.000.975	7.500	10	10	250	18.750	5%
Commercial buildings products	Tea/coffee/vending machines	30.450	50%	50%	25%	18.483.590	25.211.366	1.400	5	2	200	560	1%
	Drinking water coolers	60.750	30%	15%	15%	10.515.888	17.230.399	240	7	10	200	480	20%
	CFLs	140.000.000	12%	10%	5%	15.129.272.115	2.143.226.912	18	2	5	350	32	15%
Lighting Products	LEDs	2.708.422	15%	15%	15%	468.830.671	383.837.147	15	10	8	200	24	10%
	TFLs	186.000.000	5%	5%	5%	20.100.318.667	843.280.967	40	1	5	350	70	30%

Table 3: Main assumptions for the list of products included in the analysis

Savings potential calculation method

In this analysis, energy demand and savings are calculated according to a forecast of the number of each appliance sold, from the base year 2007 till the end of the forecast in 2030. Stock and energy consumption are calculated according to a stock turnover formalism that is common in studies assessing the potential of appliance efficiency programs, such as [4]. Energy savings depends in each year on the fraction of the stock that was sold after the assumed standard implementation date 2014. Total energy usage is calculated by considering for each product its annual Unit Energy Consumption (UEC) and the number of units in the stock by 2030 as follows:

$$total\ energy\ usage\ (MWh) = UEC\ (KWh) * Stock\ \ (Millions\ of\ unit)$$

To calculate the UEC, we considered for each product the average annual power consumption and the number of usage hours per year, as described below:

$$UEC(kWh) = \frac{Power(W) \times hours\ per\ day \times days\ per\ year}{1000}$$

For products sold after the standard, the UEC savings is given by

$$\Delta UEC = UEC \times \sigma$$

In this equation, σ is the *energy savings potential*, shown for each product in Table 1.

The affected stock, that is, the number of products installed after 2014 in year *y* is given by:

$$Stock'(y) = \sum_{i=2014}^{y} Sales(i) \times Surv(y-i)$$

where *Surv(j)* is the probability for the product to survive to age *j*

$$Surv(j) = 1 - Ret(j)$$

and *Ret(j)* is the Retirement function. We assume that *Ret (j)* will take the form of a normal distribution with mean value *L* and standard deviation L*/3.* Finally, energy savings is equal to unit savings times the affected stock, or

$$ds = \Delta UEC \times Stock'(y)$$

The sales forecast have been calculated as follows:

$$sales(y) = sales(2007) \times \prod_{i=2008}^{y} \left(1 + GR(i)\right)$$

where *GR (i)* is the growth rate in year *i*

As mentioned before, market growth rates have been estimated based on industry reports, news and trends and from industry experts' interviews. For the analysis, we considered growth trends in three time blocks (2007 to 2014, 2014 to 2020 and 2020 to 2030) to better capture the growth scenario for annual sales and estimate the future sales volume on a year-to-year basis.

In addition to final electricity savings, we also calculated greenhouse gas (CO_2) mitigation potential and avoided generation capacity, in gigawatts. Carbon dioxide mitigation potential is calculated by multiplying electricity savings by an *electricity carbon factor*, assumed to be 0.82 tonnes per megawatt hour. Avoided generation capacity is assumed to be equal to *Power(W)* in the equation above.

Result analysis

Considering the assumptions and the methodology described above, it appears that room air conditioners are the products with the highest annual energy savings (113 TWh) as well as annual peak demand reduction (79GW) and abatement potential (93 Mt CO_2eq.) Moreover, the total savings potential of cooling appliances (RACs, Chillers, Ceiling Fans, Central AC and HP) represents 30% of the total savings potential with 224TWh annual energy savings and 183 CO_2eq. Figures 2 & 4.

Motors are the highest energy demand products (1.725 TWh/yr) as opposed to RACs (754 TWh/yr). But in terms of savings potential, the estimated savings by implementing stringent requirements for RACs are almost 25% higher than the expected savings by implementing mandatory stringent requirements for motors. This can be explained by the higher efficiency improvement for RACs (15%) relative to motors (5%). This assumption is a consequence of the fact that, although motors are a very high intensity end use, they typically already operate at high efficiency, often above 90%, especially for large industrial motors. Additional savings for motors is possible through refinement of motor system design and controls, but these are not considered within the scope of the S&L program.

TVs represent the 3rd highest savings potential product; their annual energy demand is estimated to be 249 TWh. This might be explained by the high penetration of these products on Indian households. In terms of savings potential, TVs represent more than 10% of the total savings potential, [Table4].

Servers have to be considered carefully, based on the assumptions above, [Table3], their savings potential is about 21 TWh/yr. This is probably underestimated due to the lack of more accurate data.

The analysis also showed that savings potential of new products penetrating the Indian market such as washing machines, mixers, set top boxes, printers, computers, etc., represent less than 20% of the total savings potential [Table4].

Product	Annual energy demand (TWh)	Annual energy savings (TWh)	Peak energy demand reduction (GW)	CO_2 abatement potential (Mt CO_2 eq.)
RACs	754	113	79	92,8
Motors	1.725	86	35	70,7
TVs	249	62	28	51,1
Chillers	199	60	30	49,1
Ceiling fans	164	33	11	26,9
Computer servers	211	21	3	17,3
Refrigerators	124	19	5	15,3
TFLs	59	18	10	14,5
Central AC and HP	88	18	9	14,5
UPS	160	16	2	13,1
Desert coolers	54	13	9	11,1
Set Top boxes	28	12	1	9,5
CFLs	68	10	6	8,3
Computer monitors	31	8	4	6,3
Table fans/Pedestal	23	7	5	5,6
Personal computers	55	5	3	4,5
Printers	10	5	3	4,2
Exhaust fans	28	4	5	3,4
Laptops	37	4	2	3
Geysers	73	4	12	3
Washing machines	14	3	4	2,3
Laptop chargers	4	2	1	1,8
Cell phone chargers	3	2	1	1,4
Photocopiers	4	2	1	1,4
Drinking water coolers	8	2	1	0,83

Table 4: The top 25 products with the highest energy savings potential

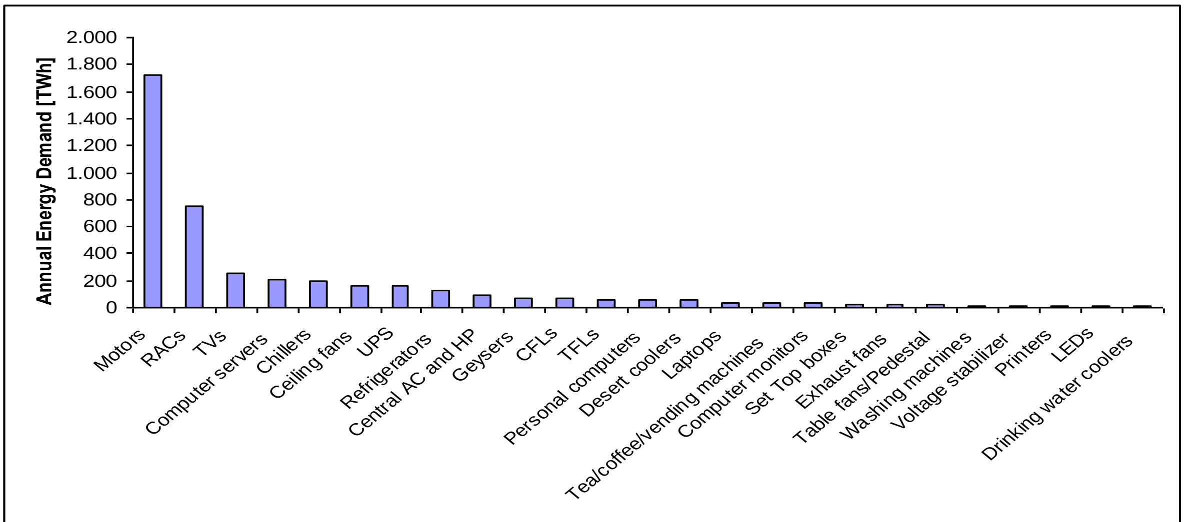


Figure 1: The top 25 products with the highest annual energy demand by 2030

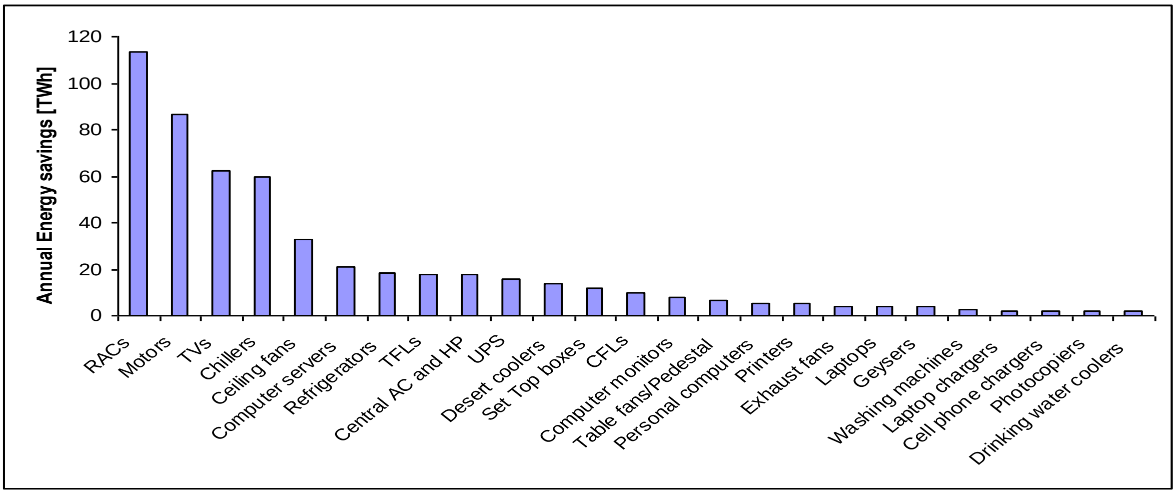


Figure 2: The top 25 products with the highest annual energy savings by 2030

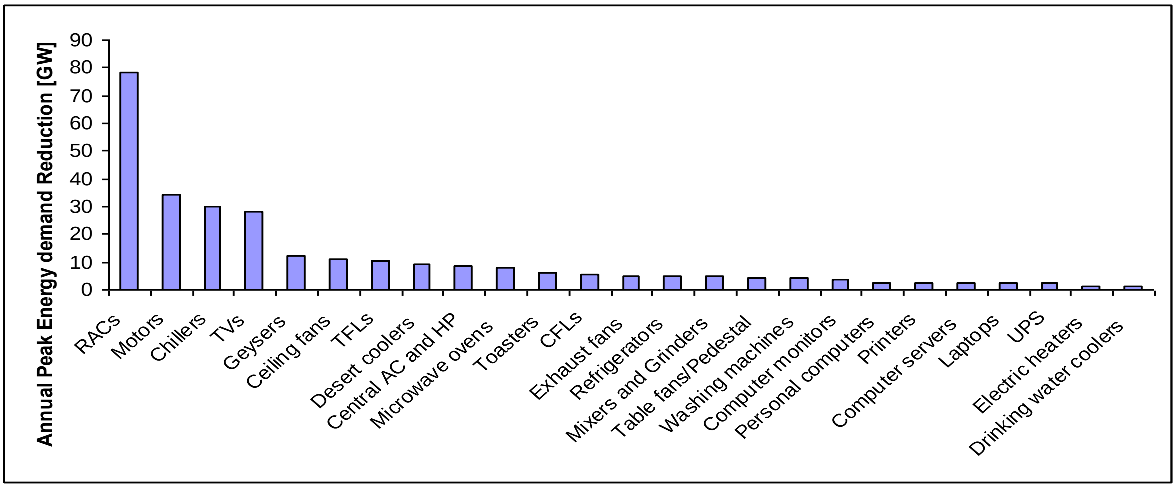


Figure 3: The top 25 products with the highest peak annual energy demand reduction by 2030

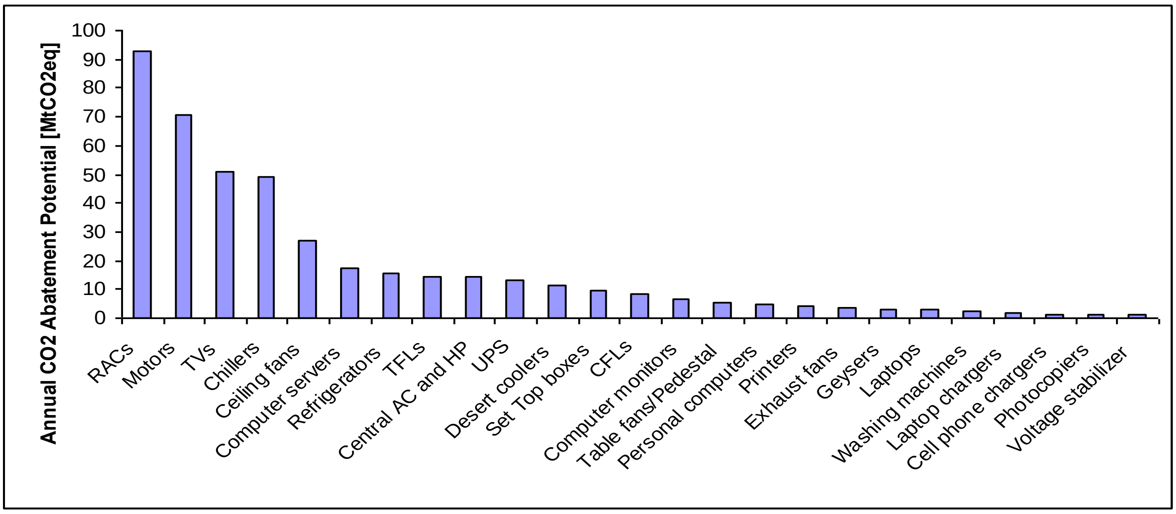


Figure4: The top 25 products with the highest annual CO_2 abatement potential by 2030

Key findings

Although room air conditioners are already regulated under S&L program in India, by 2030, their savings potential and energy demand still remain very high and will probably penalize the supply side and the Indian climate commitment. Regarding chillers, central AC and heat pumps, requirements for these products are included in the buildings code. However, since this code is voluntary, its impact is doubtful.

Motors and TVs currently regulated under the voluntary labeling program are the 2nd set of products that will highly impact the energy demand in India by 2030 even by considering an implementation by 2014 of mandatory S&L program and an increase of their efficiency by 25% for TVs and 5% for motors.

New products penetrating the Indian market will have less impact on energy demand and savings potential than cooling appliances, motors, TVs and servers.

The top 6 energy demanding products (Motors, RACs, TVs, Computer servers, Chillers & ceiling fans) are the top 6 products with the highest savings potential (RACs, Motors, TVs, Chillers, Ceiling fans & Computer servers) [Table 5].

Rank	Annual Energy Demand	Annual Energy Savings	Peak Energy Demand Reduction	CO_2 Abatement Potential
1	Motors	RACs	RACs	RACs
2	RACs	Motors	Motors	Motors
3	TVs	TVs	Chillers	TVs
4	Computer servers	Chillers	TVs	Chillers
5	Chillers	Ceiling fans	Geysers	Ceiling fans
6	Ceiling fans	Computer servers	Ceiling fans	Computer servers
7	UPS	Refrigerators	TFLs	Refrigerators
8	Refrigerators	TFLs	Desert coolers	TFLs
9	Central AC and HP	Central AC and HP	Central AC and HP	Central AC and HP
10	Geysers	UPS	Microwave ovens	UPS
11	CFLs	Desert coolers	Toasters	Desert coolers
12	TFLs	Set Top boxes	CFLs	Set Top boxes
13	Personal computers	CFLs	Exhaust fans	CFLs
14	Desert coolers	Computer monitors	Refrigerators	Computer monitors
15	Laptops	Table fans/Pedestal	Mixers and Grinders	Table fans/Pedestal
16	Tea/coffee/vending machines	Personal computers	Table fans/Pedestal	Personal computers
17	Computer monitors	Printers	Washing machines	Printers
18	Set Top boxes	Exhaust fans	Computer monitors	Exhaust fans
19	Exhaust fans	Laptops	Personal computers	Geysers
20	Table fans/Pedestal	Geysers	Printers	Laptops
21	Washing machines	Washing machines	Computer servers	Washing machines
22	Voltage stabilizer	Laptop chargers	Laptops	Laptop chargers
23	Printers	Cell phone chargers	UPS	Cell phone chargers
24	LEDs	Photocopiers	Electric heaters	Photocopiers
25	Drinking water coolers	Drinking water coolers	Drinking water coolers	Voltage stabilizer

Table 5: The top 25 products with the highest energy demand, energy savings, peak demand reduction and CO_2 abatement potential

Outcomes and Conclusions

The paper calculates energy savings potential for the list of products considered by BEE for S&L regulation and those already regulated. It shows that cooling appliances (RACs, chillers, central AC & HP and ceiling fans) represent the highest savings potential and energy demand. This might be explained by the extreme climatic conditions in India over the year and the poor quality of the building envelope. To reduce the energy consumption of cooling appliances we recommend setting mandatory requirements on cooling needs based on a holistic approach that considers buildings and equipment for both residential and commercial sectors. Other products to consider for stringent mandatory energy requirements are motors and TVs followed by computers servers. A systemic approach is recommend for motors to better capture their savings potential.

The total estimate of the annual energy savings potential for the products used in the buildings sector in India is 535 TWh with 113 TWh savings from RACs and 223 TWh from cooling appliances (RACs, Chillers, central AC &HP and ceiling fans) which is more than the double of the estimate (105 TWh) of the savings potential of new products (UPS, desert coolers, set top boxes, CFLs, computers monitors, table fans, personnel computers, printers, exhaust fans, laptops, geysers, washing machines, laptop chargers, cell phone chargers, photocopiers, drinking water coolers, stabilizers, fax machines, microwaves, LEDs, inverters, mixers and grinders, vending machines, toasters, electric heaters, DVD players, music systems, water purifiers, scanners, routers, modems, iron, vacuum cleaner, cordless phones, immersion heaters, electric hard disc drives). However, the contributions of some of these products to the peak demand reduction may be high.

A framework model has been developed for the purpose of this study. It provides BEE with a methodology for assessing energy demand and savings potential that is achievable by the Indian S&L program by 2030. The framework model is flexible enough to allow BEE to adjust all the parameters when more data are available.

The study represents an initial benchmark to assess potential savings and energy demand for electric products considered for regulation by BEE, further refinement of the assumption is needed to update the next S&L strategy in India.

References

[1] Notification on Indian Gazette available on http://220.156.189.25:8080/beeLabel/Schedules/Schedule3-RAC.pdf

[2] Notification on Indian Gazette available on: http://220.156.189.25:8080/beeLabel/Schedules/Schedule1-%20for%20Frost%20Free%20refrigerators.pdf

[3] Environmental design Solutions. *Assessing energy demand and savings potential for specified appliances and equipment in India.March 2010*.

[4] McNeil, M.A., M. Iyer, S. Meyers, V.E. Letschert and J.E. McMahon. *Potential benefits from Improved Energy Efficiency of Key Electrical Products: The case of India.* Energy Policy 36 (2008) 3467-3476.

The impact of innovation on market structure for EuPs and how this can be built into policy impact assessments

Adrian TAN, François COHEN, Shailendra MUDGAL, Franck CACHIA. BIO Intelligence Service, Paris, France

Roger SALMONS, Robin VANNER. Policy Studies Institute, London, UK

Abstract

A number of policy interventions and initiatives have been put place in the EU to improve the energy efficiency of energy-using products (EuPs). Most notably the Energy Labelling Directive and the Ecodesign Directive have already resulted in significant reductions in energy consumption and corresponding greenhouse gas emissions, with further reductions expected in the coming years. While these product policies are typically thought to impose additional costs on producers and increase the purchase price for consumers (not the life cycle costs) of EuPs, several studies have shown that innovation may in fact reduce the magnitude of regulatory costs. If this is the case, then it is important that the impacts of innovation are understood and taken into account in policy impact assessments.

This paper summarises the findings from a Defra (UK Government) funded study[1] where the impacts of innovation were examined in relation to the regulatory costs faced by product manufacturers in response to EuP polices. Based on evidence found in literature and analysis of empirical UK market data (fridges, dishwashers, washing machines, ovens and cookers), a market-based approach to account for the impacts of innovation was developed. Compared to the cost-based engineering approach of current impact assessments, the methodology developed is able to predict future sales and price trends by analysing the evolution of the market structure of EuPs in relation to their energy efficiency performance. This paper presents this new market-based methodology which accounts for the impacts of innovation and discusses how it can be used to better estimate the ex ante costs for consumers and manufacturers in policy impact assessments. The proposed market-based approach should however be used in a complementing manner with the conventional cost-based approach and expert opinion.

Keywords: *energy efficiency; product policy; innovation; learning curves; market diffusion*

Introduction

Energy-using products (EuPs), such as refrigerators, televisions, motors and lighting, contribute significantly to the CO_2 emissions through their consumption of energy during use. It is generally accepted that policies that encourage the use of more energy efficient products can generate significant reductions in overall energy consumption and, hence, CO_2 emissions cost-effectively. Over the past decades, the European Union has put in place a number of product policies such as the Energy Labelling Directive, Ecodesign Directive and Energy Star Programme, to improve the energy efficiency of EuPs. While product policies aim to provide cost and environmental benefits on the long term, they may impose costs on the producers and consumers in the short run. The cost and benefits (economical, environmental and social) of policies in the EU and in the UK are always assessed prior to their introduction.

Existing impact assessments typically estimate the regulatory cost of a particular EuP policy intervention on a firm or group of firms by the change in profit relative to the non-intervention counter-

[1] Policy Studies Institute and BIO Intelligence Service *Impacts of Innovation on the Regulatory Costs of Energy-using Product Policy* (February 2011). Can be downloaded at http://randd.defra.gov.uk/Document.aspx?Document=EV0703_10122_FRP.pdf

factual. For consumers, this is given by the change in the market price. These changes may be driven by a number of factors:

- increased administration costs, due to monitoring and reporting requirements, certification costs, etc;
- decreased unit profitability of existing products due to the inability to fully pass-on increased unit production costs to consumers in product prices;
- additional investment costs involved in the development and production of new products (that were not previously deemed profitable – i.e. had negative net present value (NPV));changes in the mix of products sold;
- changes in the consumers' willingness-to-pay for products.

The change in profit in UK policy impact assessments are typically calculated using an 'engineering' cost-based approach. Under this approach, estimates are made – through consultation with product experts – of the incremental costs of any new technology and / or product changes that would be required to meet the energy efficiency improvements implied by the policy intervention. This cost is then assumed to be passed on fully to consumers (i.e. there is 100% pass-through of any additional product cost). While this approach has the merit of simplicity, it suffers from three major difficulties:

- information on costs is often confidential and therefore it can be difficult to obtain robust estimates for the increases in unit cost.
- the pass-through to consumers is not measurable with the available data and hence the allocation of the costs between manufacturers and consumers cannot be analysed. Consequently, only the net policy cost can be calculated.
- it does not provide a systematic framework for measuring the influence of innovation and economies of scale on market shares and costs.

Several studies [1,2,3] have however shown that the cost of policies and regulations to companies, when calculated ex-post, can be very different – and frequently lower – that the initial ex ante estimates. One factor that has been identified as potentially important in explaining this divergence is the effects of innovation.

Defining innovation

Innovation is understood here as the introduction of new, more energy-efficient products on the market and their accelerated diffusion. There is considerable evidence in the literature that a 'natural' phenomenon occurs in manufacturing firms, where the average unit cost of a product declines with cumulative production. This is due to 'economies of scale', but also due to so-called 'experience curve effects'. For a wide range of energy-using products, learning rates (the constant rate costs/prices decline with each doubling of cumulative production) have been observed.

Weiss et al. (2010a) [4] performed a comprehensive review of studies that have estimated experience curves for energy using products. The studies included in the review cover a range of different technologies and countries; with varying time-spans over the last one hundred years (i.e. 1909-2008). They found that the learning rates for energy-using products exhibit almost a normal distribution, with a mean value of around 18% (i.e. costs decrease with 18% with each doubling of cumulative production). There is a relatively wide spread around this mean value, with technology-specific learning rates estimated by individual studies ranging from 4% (for condensing gas boilers) to 41% (for compact fluorescent light-bulbs). The average learning rates of products, based on various studies, range from 9% (for refrigerators) to 26% (for consumer electronics), see table 1.

Table 1. Learning rates for various energy-using products

Technology	No. of studies	Average	Confidence interval
Residential heating	6	10%	± 8%
Air conditioners	6	16%	± 6%
Washing machines	2	23%	± 14%
Laundry dryers	5	14%	± 8%
Dishwashers	4	16%	± 8%
Refrigerators	3	9%	± 3%
Freezers	3	13%	± 8%
Compact fluorescent light bulbs	8	21%	± 8%
Lamp ballasts	6	12%	± 13%
Television sets	4	16%	± 8%
Other consumer electronics	4	26%	± 3%
All technologies[2]	**75**	**18%**	**± 9%**

Source: Weiss et al. (2010a) [4]

The analysis of EU sales data clearly shows that improvements in energy efficiency is reflected in a continuous evolution of the market share of energy efficiency labels over time; with higher energy classes entering the market and increasing their market share, while lower classes lose market share and then leave the market. This process is clearly illustrated in the case of fridges in the UK, where there was a dramatic transformation of the energy class profile over an eight year period (see Figure 1). While the speed of the evolution varies between product categories, the process is common to all energy-using products targeted by product policies.

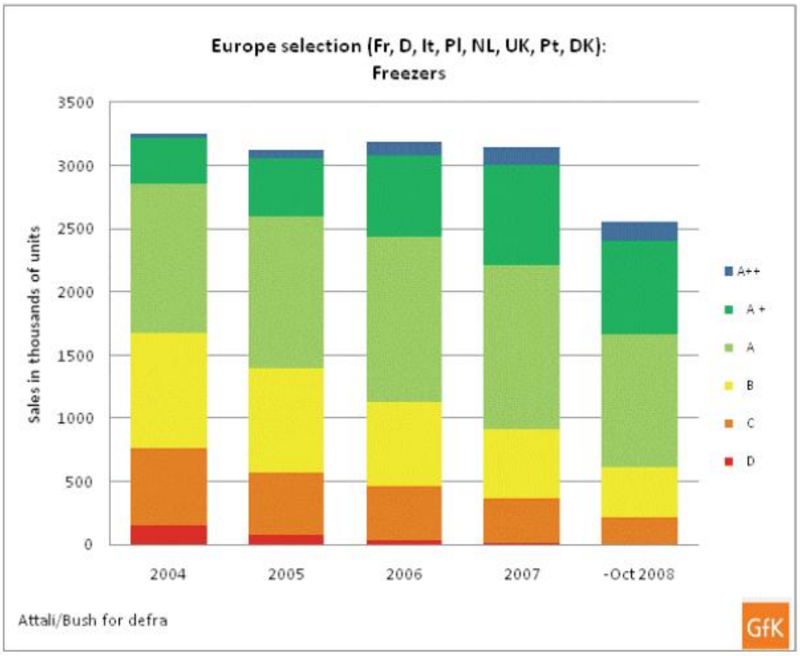


Figure 1. The evolution of energy class market shares in selected EU Member States

Source: GfK market data [5]

A few studies have looked at the effect of the introduction of higher energy-efficiency standards on the purchase price of EuPs. Newell et al. (1999) [6] compared the impact of energy efficiency standards and energy prices on the rate of energy efficiency improvement of air conditioners and gas water heaters, using data assembled from US sales catalogues from 1958 to 1993. They found that government energy efficiency standards for air conditioners introduced in 1990 had an effect on the rate of efficiency improvement; although efficiency improved a few years before as new models were introduced that anticipated the future standards.

---

[2] Not all included in the table

Schiellerup (2002) [7] looked at the effect in the UK of the introduction in 1999 of EU minimum standards for the efficiency of cold appliances. A study by the Group for Efficient Appliances in 1993 had identified a least life cycle cost (LLCC) potential of 38–50% for cold appliances (depending on product type) compared with models on the market in 1990–1992. However, the standard required only a 15% reduction in the energy consumption of the average new cold appliance by 1999 over the 1990–1992 levels, reflecting a compromise between the Commission, industry, the Energy Council and the European Parliament. The introduction of the standard had an immediate impact in the UK. There was a 14% increase in the energy efficiency of appliances sold in the UK over the fifteen months January 1999 – March 2000, as models that met the standard moved from a minority of sales to become dominant on the market. For some products, the improvement was even greater (e.g. 24% for chest freezers), although this may have been due to UK products being less efficient than those sold in the rest of the EU. This compared with a rate of improvement in efficiency over the previous ten years of only around 2% per annum. However, the introduction of the standard had no apparent impact on the downward trend in prices. The weighted average price of appliances fell at an annual rate of 6% following the introduction of the standard, compared with an average decline of 3% per annum in the four years preceding its introduction. This leads the author to conclude that the standard could have been much more ambitious, lowering life cycle costs much further.

A more recent study by Dale et al. (2009) [8] compared the US Department of Energy's (DOE) predictions for the price impact of meeting higher efficiency standards with the changes in actual prices when those standards were introduced. Interestingly, rather than increase when the efficiency standards were raised, as had been predicted, they found that prices continued to decrease. On the basis of the results of a regression analysis for a simple hedonic price model, the authors conclude that the divergence between predicted and actual prices can be explained by a combination of overall (or neutral) technological change lowering the cost of all appliances over time; efficiency-directed technological change reducing the relative cost of higher efficiency models; declining distribution mark-ups as markets became more competitive; economies of scale in the production of higher-efficiency models as these increased their share of the market. They also compared the DOE's estimates of the price impacts of a unit increase in energy efficiency (termed by the authors as the "cost of energy efficiency") with the actual impacts derived from their regression analysis. The DOE estimates were based on a "bottom-up" engineering analysis of the unit production costs for different levels of energy efficiency; with the price impact being determined by applying a fixed mark-up on costs of 100%. Consequently, the inferred impact on unit costs is equal to half the predicted price impact. For refrigerators (and room air conditioners), DOE estimates were provided for two time periods. Comparison of these estimates shows that the cost of energy efficiency declined by around two-thirds between the two assessments (i.e. between 1989 and 1995), reflecting efficiency-directed technological change mentioned above.

Following the investigations of experience curves for EuPs, Weiss et al. (2010b) [9] estimated learning rates for specific price and for specific energy consumption for five different white good categories in the Netherlands for the period 1964-2008. They found a steady decline in both price and energy consumption of appliances over the period, indicating that the introduction of novel and initially expensive energy efficiency technologies does not necessarily imply adverse price effects in the long term. For dishwashers, refrigerators and freezers there was a significant acceleration in the decline of specific energy consumption from the mid-1990s onwards, with learning rates more than doubling.

Table 2: Comparison of cost-based and price-based learning rates

Technology	**Specific price**		**Specific energy consumption**	
	Mean	**Confidence Interval**	**Mean**	**Confidence Interval**
Washing machines	33%	± 9%	35%	±3%
Laundry dryers	28%	± 7%	20%	± 6%
Dishwashers	27%	± 7%	18%	± 3%
Refrigerators	9%	± 4%	17%	± 2%
Upright freezers	10%	± 5%	13%	± 3%
Chest freezers	8%	± 2%		
Average	**19%**	**n/a**	**21%**	**n/a**

Source: Weiss et al. (2010b) [9]

The authors attributed this to the introduction of the EU energy labelling scheme and minimum performance standards in 1992 and 1996 respectively, and the Dutch energy premium regulation introduced in 2000; concluding that energy policy is to some extent able to increase the slope of energy experience curves.

Both the US studies show that the energy efficiency of appliances could be increased at lower cost than expected. The UK study seems to indicate that efficiency was increased for a negligible cost. In both cases, the standards were met through the increased diffusion of existing technologies rather than the introduction of new technologies.

From the studies it would seem that product policy interventions appear to have accelerated the rate of improvement of energy efficiency, without affecting the long term downward trend in prices. The studies suggest that policy interventions only have a short-run impact on average product costs and prices – i.e. the regulatory costs are relatively short-lived. Consequently, it is important that the impact of innovation is explicitly taken into account when undertaking impact assessments of potential policy interventions. If this is not done, there is a risk that minimum energy performance standards are not set ambitiously enough and do not result in the expected energy savings.

Estimating the impacts of innovation

This paper presents a new market-based approach for estimating regulatory costs in policy assessments by taking the impacts of innovation into account. The approach described in this paper is based on a study [10] performed by Policies Studies Institute (UK) and BIO Intelligence Service (France) for the Department for Environment, Food and Rural Affairs (Defra) in the UK to support product analysts in the Market Transformation Programme (MTP) when carried out policy impact assessments. Based on the analysis of UK market data of certain EuPS, there appears to be a stable and predictable relationship between the relative energy efficiency of a product (or class of products) and the market structure in terms of relative prices and market shares. This is then used to lay the foundations for a new framework for taking the impacts of innovation in policy assessments.

Methodology and data

Inspired by Dale et al. [8], a pricing model was developed on which multiple linear regression analysis was performed on UK market data provided by Defra for domestic white goods. The market data included datasets of retail prices, size, features, energy label, etc. for representative models of refrigerators, fridge-freezers, washing machines, dishwashers, ovens and cookers sold in the UK between 2000 and 2007. Multiple linear regression analysis allows the effect of individual parameters to be separated from others. As a proxy for innovation, an indicator called the *Efficiency Ranking Index* (ERI) was developed. ERI is the relative market position of a product or energy class with respect to its Energy Efficiency Index (EEI)[3]. It expresses how innovative an EuP is in terms of its energy efficiency compared to the rest of the market, e.g. the most energy efficient appliance on the market has an ERI of 1, whilst the least efficient has an ERI value of 0.

The regression analysis was performed according to the following econometric price model:

$$Price_{ijt} = \sum_{k}^{features} a_{1k}.feat_{ik} + \sum_{p}^{labels} a_{2p}.\mathbb{1}[efficiency_i = p] + a_3.sold\ units_{it} + a_4.brand\ position_j + a_5.\boldsymbol{efficiency\ ranking}_{it}$$

For any product ***i*** from brand ***j*** in the year observed ***t***, price is dependent on all general features ***k*** (**feat**), its energy efficiency class (***efficiency*** is divided into variables taking the value 1 or 0 according to the actual efficiency label ***p*** of ***i***), the number of sold units (***sold units***), the ***brand position*** on the market (brand position) and the ERI (***efficiency ranking***). The ***a*** and ***b*** terms are coefficients to be estimated using multiple regression analysis on panel data including random effects at the model level. Prices are corrected for inflation and expressed in 2005 pounds according to the Consumer Price Index (CPI) published by the Office for National Statistics.

---

[3] As defined by the Energy Labelling Directive

Table 3. Overview of market datasets

Appliance type	Years	Number of observations	Number of sold units in 2005	Energy efficiency parameter
Fridges	2000 – 2007	5,049	1,055,209	EU Mandatory Energy Labelling (A++ to G)
Fridge-freezers	2000 – 2007	7,667	1,533,690	EU Mandatory Energy Labelling (A++ to G)
Dishwashers	2005 – 2007	2,665	851,337	EU Mandatory Energy Labelling (A to G)
Washing machines	2003 – 2007	4,060	2,488,365	EU Mandatory Energy Labelling (AAA to GGG) CECED Voluntary Commitment (A+ and A++)
Ovens	2005 – 2007	3,044	567,417	EU Mandatory Energy Labelling (A to G) for electric ovens
Cookers	2005 – 2007	2,274	664,171	

Source: GfK market data

Unfortunately the market data only provided information on sales prices and not manufacturing costs which was the actual focus of the study. As data on manufacturing costs is considered confidential by most companies, estimates had to be made of the margins (or mark-ups) of retail prices relative to manufacturing costs. Estimates of margins were derived from a variety of different studies that considered the manufacturing costs of domestic appliances [11,12,13].

Results of the empirical analysis

The regression analysis allowed the growth of market shares of energy efficient models and their change in sales prices to be observed, whilst controlling for all other differentiating product characteristics such as size, features, brand, etc. Figure 2 shows an example of the results for fridges.

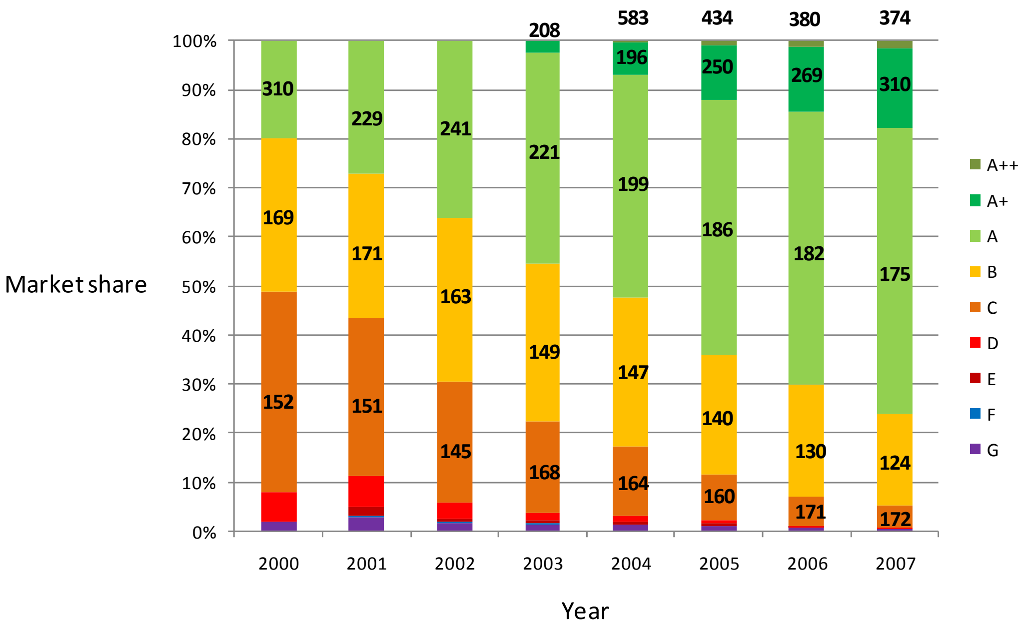


Figure 2. The evolution of energy class market shares and average prices (in GBP) for fridges in the UK

Source: GfK market data

Link between energy efficiency and retail price

The empirical analysis confirmed the general trend that the average energy efficiency of products on the market was increasing at the same time as the average sale prices were decreasing. The regression analysis showed that there even was a sufficient statistical correlation between the efficiency ranking (ERI) and retail prices to develop an econometric model that could predict the price evolution of energy efficient products. It was observed that, all else being equal, products with higher ERI values commend higher prices on the market. The difference between the price of the most efficient product (ERI = 1) and the least efficient product (ERI = 0) is termed the "*efficiency premium*". Basically, it could be shown that the most energy efficient (and innovative) products commend the highest prices on the market, but their prices fall rapidly if even more energy efficient (and innovative) products enter the market.

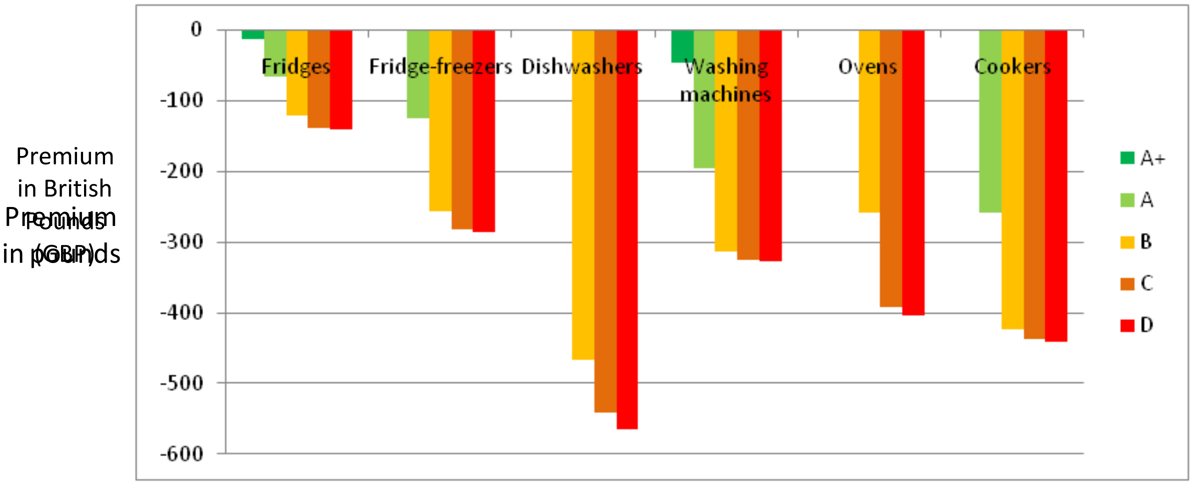


Figure 3. Estimates of price differences between the best available label and other labels correlated with ERI differences in 2007. Prices in British Pounds (GBP).

Source: GfK market data

Link between market position and sales

In a similar manner that a relation between prices and innovation could be determined through statistical analysis, the relation between ERI and sales was also analysed. This was done by comparing the ERI values by efficiency class for fridges, fridge-freezers and washing machines with the total sales of each efficiency class. As the annual sales in a given product category evolve over time, a correction was made to total sales by efficiency class so that the annual sales by product category were kept constant. This correction allowed different sales levels for different years to be compared. The graphs below illustrate the comparison between total sales and the ERI for fridges. Similar graphs were obtained for fridge-freezers and washing machines.

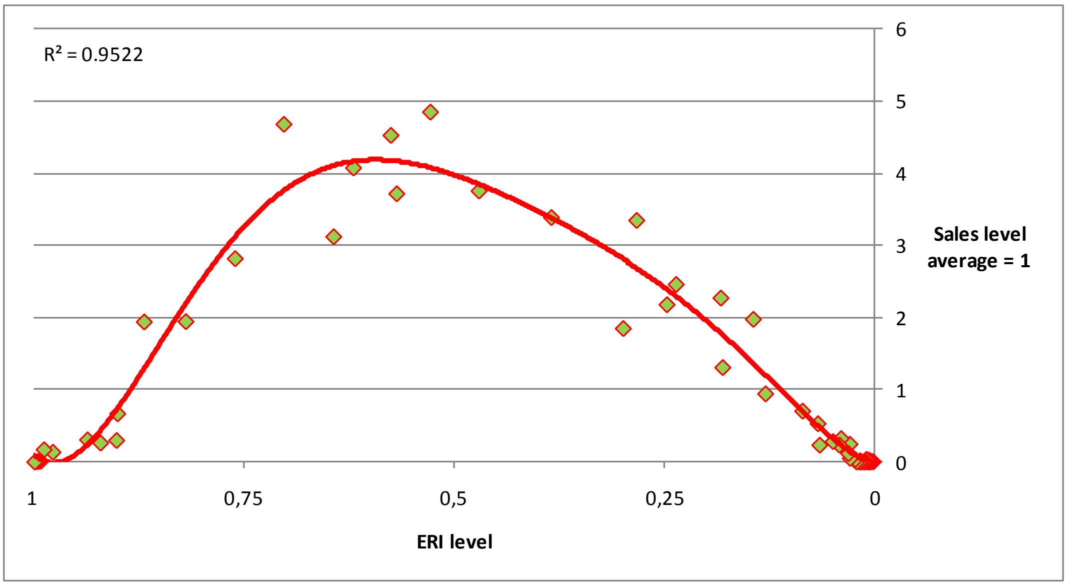


Figure 4. The link between the 'innovativeness' of an efficiency class and its sales potential for fridges

Source: GfK market data

The sales level according to the innovative content of products seems well represented by a bell-shaped curve slightly skewed towards the right. This skew may be caused by a bias in the representation of the less innovative models in the GfK datasets. This bias is very likely because the less innovative models are also the models that are the less sold in the GfK datasets. Therefore, a fairly plausible shape is a symmetric bell-shaped curve. This curve could serve as an inter-temporal reference to construct sales forecasts.

From this the relationship between the ERI value for an energy class and the change in its market share from one time period to the next could be determined. The analysis of market data for a number of product categories suggests that changes in market share tend to exhibit a common "sine wave" profile (see Figure 5 for the case of fridges). Energy classes in the top half of the efficiency ranking (i.e. with ERI > 0.5) increase their market share – with the increase being greatest when the ERI value is around 0.75. In contrast, energy classes in the bottom half of the ranking (i.e. with ERI < 0.5) lose market share – with the loss being greatest when the ERI value is around 0.25. Thus, given the average ERI values of the different energy classes at any point in time, it is possible to estimate the annual change in market share and hence project future market shares.

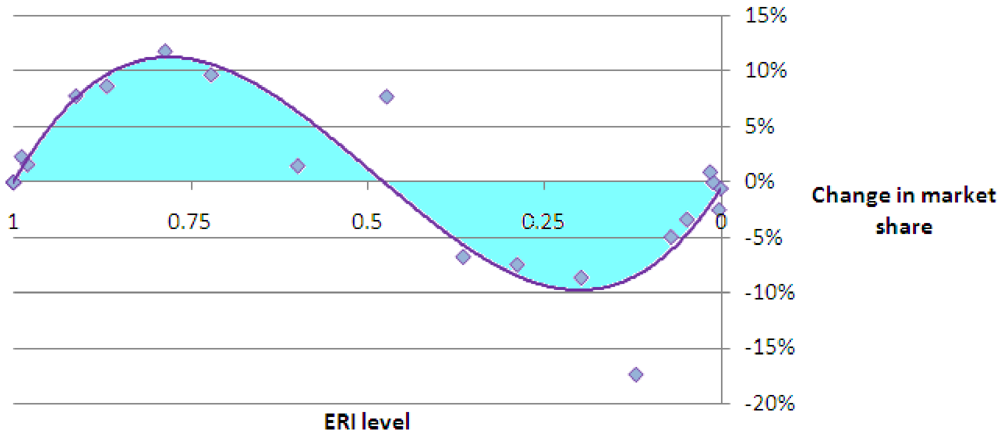


Figure 5. Relationship between ERI and change in market shares for fridges

Source: GfK market data

A framework for accounting for innovation in policy impact assessments

Contrary to the conventional 'engineering cost-based' approach to estimating regulatory costs, a market-based approach based on the rate of replacement and appearance of new models on the market could be used to take into account the impacts of innovation. This would be calculated based on a statistical analysis of existing market data. As was seen, the empirical analysis provided sufficient evidence about the relationship between energy efficiency, prices and sales, which could be used to determine the evolution of market shares and average sale prices. Consequently, the cost of a policy intervention can be calculated by considering how the resultant change in the structure of the market, in terms of the relative energy efficiency, affects the evolution of market shares and prices. Unlike the cost-based approach, this does not require any estimates to be made of the impact on product costs, but is based purely on available market data.

Thanks to the above a new framework for assessing the regulatory costs of product policy was developed. The framework takes into account the effects of innovation and is based on three key concepts identified in literature and the empirical analysis:

- The appearance of new, energy efficient product models on the market changes the competitive market position of all the products on the market (i.e. the diffusion of new energy efficiency products).
- Policy interventions can influence the rate at which high energy efficiency products enter the market and low efficiency products exit the market (i.e. the rate of innovation in relation to energy efficiency).
- High efficiency products can command higher prices in the market (i.e. the willingness-to-pay for energy efficient products).

Price and sales predictions for energy efficient products

Using the metrics for market position in relation to innovation (ERI) and efficiency premium, the evolution of a product's price and sales volume can be related to its market position in terms of energy efficiency. A third metric was developed to represent the rate at which innovation was occurring on the market. This was done by estimating the time it would take for the most efficient class of products on the market (ERI = 1) to become the least efficient (ERI = 0). This metric was named *'energy efficiency class life'* and was influenced by product policy. Minimum energy performance standards determine when an energy class becomes obsolete and labelling defines new high energy efficient classes.

Once this parameter is calculated, a recursive process relating the innovative content of products to price and sales levels produces the market forecast. Figure 6 represents the dynamics of the ERI model to forecast the evolution of prices. According to the energy class life and the premium associated to innovation, the price of an innovative product steadily decreases until it becomes obsolete and is dropped from the market. The definition of innovation in terms of ERI allows quantifying the pace and extent of such a price decrease.

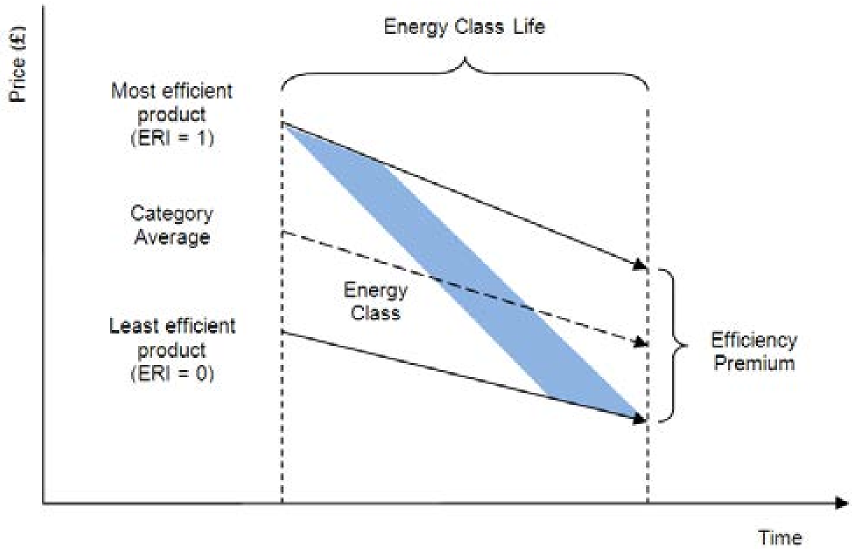


Figure 6. Relationship between the three metrics used to estimate product prices and sales volumes according to energy efficiency

The market-based approach proposed here takes into account innovation in a consistent and coherent way as it is founded on the market dynamics of the diffusion process. The data requirements are based on actual (historical) market data on product prices and sales, and the entire framework is captured in a simple set of metrics.

Testing the framework

Based on the framework presented above an Excel-based simulation tool was developed and tested on four different types of EuP, where impact assessments had already been carried out. The simulation tool generates projections of energy class market shares and average prices under two scenarios: a reference scenario (i.e. without the intervention) and a policy scenario (i.e. with the intervention). Comparison of the two projections allows the impacts of the intervention on consumers' expenditure and producers' profits to be derived. Three types of policy intervention can be modelled under the policy scenario, either individually, or in combination:

1. Minimum energy performance standards that prohibit the sale of energy classes below a specified level.

2. Minimum technical requirements that stipulate the addition of compulsory product functions and / or components

3. Labelling and other demand-side measures that encourage consumers to change their purchasing behaviour and to buy more efficient products.

The simulation tool was tested in four case studies, covering a range of energy-using products: i.e. fridges, light bulbs, televisions and electric motors. It proved possible to apply the approach – and the simulation tool – in three of the four cases. Application of the tool in the cases of fridges and motors was relatively straightforward, although the latter required the use of one of the tool's optional features to model complex policy scenarios. However, applying the tool in the cases of televisions and lighting was more challenging due the number of alternative technologies available (e.g. CRT, LCD, plasma televisions) and the rapidly evolving technology mix. In the case of televisions, this was overcome by assuming that policy interventions had no impact on the evolution of the technology mix and then applying the tool to each screen technology individually with the resultant costs being aggregated. For lighting, the nature of the policy intervention (i.e. specifying a performance level that in practice banned a particular technology from the market) meant that this assumption could not be made and hence it was not possible to apply the tool in this case.

Evaluation of the accounting framework

The market-based approach developed in this project has a number of advantages over the current cost-based assessment approach. Most importantly, because it is founded on the market dynamics of the diffusion process, the effects of innovation are automatically taken into account in a consistent and coherent way. Furthermore, it does not require any (potentially confidential) information regarding the identities and costs of new technologies; the necessary inputs being calculated from actual (historical) data on product prices and sales.

However, while the predicted impact on the average prices and shares of energy classes is based on empirically derived relationships, the impact on producer profits (and hence the net impact of the intervention) relies on assumptions about the level and structure of product margins – neither of which has any empirical support. This contrasts with the current cost-based approach, where the impacts on unit production costs are based on expert technical opinion. Furthermore the impact on purchase prices is based on an assumption regarding the pass-through of this cost increase, which again is not supported by any empirical evidence. Thus, while the market-based approach is likely to provide a better prediction of the impact on energy class shares and average prices, the cost-based approach is likely to provide a better indication of the impact on unit costs (provided that account is taken of learning effects).

As was discovered in the case of televisions and lamps, the framework for accounting for the impacts of innovation is limited to estimating the regulatory costs of EuP policies for a given technology. It cannot predict major technological shifts and model price premiums for different technologies that exist on the market at the same time, i.e. it works well with incremental technological innovation and not radical innovation. The more heterogeneity in terms of product technology there is within a product group (e.g. incandescent lighting, compact fluorescent lighting, halogens, etc.), the more imprecise the estimation will be, particularly if this has an impact on the way the policy scenario is modelled. Similarly, the framework is not able to deal with different product lifetimes for each product category because calculation of the total sales estimate does not take into account these differences in lifetime. Theoretically, it would be possible to develop the framework to integrate such aspects, but this would compromise the simplicity.

For most product categories, it should not be difficult to have a general idea about most inputs (e.g. market shares, efficiency class life, total sales evolution and price evolution). However, it is difficult to know whether the value of each parameter is correct. Therefore the framework should not be used to replace expert opinion about the evolution of sales and prices when introducing a new product policy. The framework and the developed simulator is a tool which can be used in an active manner, where the data and parameters can be easily modified with input from expert opinion and the judgement of product analysts about price variations and consumer behaviour.

Finally, as the analysis in this study was only performed on a limited number of product categories and years where market data was available, it is recommended that the analysis is repeated for later market data, when it becomes available. In this way the approach proposed can be checked and verified with other data sets.

Conclusion

This study set out to examine the role of innovation in the context of regulatory costs imposed on consumers and manufacturers by EuP policy interventions. Based on the existing literature and empirical analysis of UK market data, it was found that innovation has a major impact on the costs, prices and energy efficiency of EuPs. Consequently, it is important that this is taken into account explicitly and consistently when undertaking impact assessments of potential policy interventions.

The diffusion of more efficient products (and hence higher energy classes) appears to be a market-driven process, with predictable impacts on structure of the market in terms of both relative prices and sales. This suggests that it may be better to use a market-based approach when assessing the impacts of policy interventions on market prices (i.e. considering the expected impacts on the market structure), rather than the engineering / cost-based approach currently employed.

The market-based approach developed in this project has a number of advantages over the current cost-based assessment approach. Most importantly, because it is founded on the market dynamics of the diffusion process, the effects of innovation are automatically taken into account in a consistent and coherent way. Furthermore, it does not require any (potentially confidential) information regarding the identities and costs of new technologies; the necessary inputs being calculated from actual (historical) data on product prices and sales.

However, the approach also has a number of limitations. In particular, while the predicted impact on the average prices and shares of energy classes is based on empirically derived relationships, the impact on producer profits (and hence the net impact of the intervention) relies on assumptions about the level and structure of product margins – neither of which has any empirical support. This contrasts with the current cost-based approach, where the impacts on unit production costs are based on expert technical opinion, and the impact on prices reflect an assumption of the pass-through of this cost increase. Again, this is not supported by any empirical evidence. Thus, while the market-based approach is likely to provide a better prediction of the impact on energy class shares and average prices, the cost-based approach is likely to provide a better indication of the impact on unit costs (provided that account is taken of learning effects).

Consequently, while each approach can be used in isolation to estimate the impacts on consumers and producers, there would appear to be benefits in using the two approaches in combination; with the market-based approach (and simulation tool) being used to assess the impacts on the average prices and market shares, while the cost-based approach is used to assess the impacts on average unit costs. The respective outputs can then be brought together to calculate the impacts on consumers and producers – and hence the net impact of the intervention. Whatever the choice of method, the importance of expert opinion regarding the evolution of sales and prices, when introducing a new product policy, should be taken into consideration.

References

[1] Michael MacLeod M., Moran D., Aresti M. L., Harrington W., Morgenstern R. *Comparing The Ex Ante And Ex Post Costs Of Complying With Regulatory Changes*. Study by SAC Commercial Ltd and Resources for the Future for Defra, UK. (March 2006). Can be downloaded at: http://www.defra.gov.uk/evidence/economics/foodfarm/reports/documents/finalriaexantiexpost.pdf

[2] Oosterhuis F. et al. *Ex-Post Estimates Of Costs To Business Of EU Environmental Legislation*. Study by IVM, BIO, Ecologic, GHK, PSI, TME and VITO for the European Commission, DG Environment. (April 2006). Can be downloaded at: http://ec.europa.eu/environment/enveco/ex_post/pdf/costs.pdf

[3] Skinner I., Boyd R., Pett M. and Watkiss P. *Assessing How The Costs And Benefits Of Environmental Policy Change Over Time.* Study by AEA for the European Commission, DG Environment (August 2007) Can be downloaded at: http://www.cafe-cba.org/assets/costs_and_benefits_of_policy_change_over_time.pdf

[4] Weiss M., Junginger M., Patel M.K., Blok K. *A review of experience curve analyses for energy demand technologies*. Technological Forecasting & Social Change. (2010a) Vol. 77, pp. 411–428

[5] Attali S., Bush, E. and Michel A. *Factors influencing the penetration of energy efficient electrical appliances*. Study by SoWATT and Bush Energie Gmbh for Market Transformation Programme (MTP) / Defra. (June 2009). Can be downloaded at: http://www.mtprog.com/cms/library-publications/

[6] Newell R.G., Jaffe A.B. and Stavins R.N. *The induced innovation hypothesis and energy-saving technological change*. The Quarterly Journal of Economics. (1999) 114(3), pp. 941-975

[7] Schiellerup P. *An examination of the effectiveness of the EU minimum standard on cold appliances: the British case.* Energy Policy (2002) 30, pp. 327-332

[8] Dale L., Antinori C., McNeil M., McMahon J.E. and Fujita K.S. *Retrospective evaluation of appliance price trends*. Energy Policy (2009) 37, pp. 597-605

[9] Weiss M., Patel M.K., Junginger M. and Blok K. *Analysing price and efficiency dynamics of large appliances with the experience curve approach*. Energy Policy (2010b) 38, pp. 770-783

[10] Salmons R., Vanner R., Mudgal S., Tan A., Cohen F. and Cachia F. *Impacts of Innovation on the Regulatory Costs of Energy-using Product Policy*. Study by Policy Studies Institute (PSI) and BIO Intelligence Service for Defra, UK. (February 2011). Can be downloaded at http://randd.defra.gov.uk/Document.aspx?Document=EV0703_10122_FRP.pdf

[11] Dale L., Millstein D., Coughlin K., Van Buskirk R., Rosenquist G. and Lekov A. *An Analysis of Price Determination and Markups in the Air-Conditioning and Heating Equipment Industry.* Lawrence Berkeley National Laboratory. (2004). LBNL Paper LBNL-52791.

[12] Mebane B. and Piccinno E. *The cost-effectiveness of production tax credits in transforming the market for home appliances and harnessing manufacturers competitiveness*. Study for CECED. (2006).

[13] CECED. *Energy-efficiency: a short cut to Kyoto targets*. European Committee of Domestic Equipment Manufacturers. (2006).

Impact assessment of refrigerators and room air conditioners voluntary labeling program in India

Tanmay Tathagat

Yamiha Saheb

Keywords: Voluntary Label, Impact assessment, India, Air conditioners, Refrigerators

Abstract:

Over the past decade, the Indian economy has grown rapidly, leading to a significant increase in energy demand. To reduce the energy needs, the Indian Government passed the Energy Conservation Act in 2001, which stipulates the implementation of labeling and standards programs for notified products.

Following the adoption of the Energy Conservation Act, the Bureau of Energy Efficiency (BEE) launched the standards and labeling program in 2007. During the 1st phase of its implementation (2007-2009), the labeling program for room air conditioners and domestic refrigerators was voluntary.

Early 2010, the labeling program has become mandatory and a minimum threshold for each energy band has been implemented as well as a rescaling schedule (2010-2015) to remove the less efficient appliances from the market.

To ensure a successful implementation of the labeling program for domestic refrigerators and room air conditioners, BEE has conducted an intensive communication campaign to raise energy efficiency awareness among consumers, manufacturers and retailers throughout the country.

A comprehensive impact assessment analysis has also been conducted to estimate the impact of the voluntary program from energy, environment, and cost-benefit perspectives, for the consumers as well as the country. The analysis showed energy savings of 895 GWh, resulting in 0.70 Mt CO_2 eq. emission reductions and 629.2 MW of avoided capacity for the year 2008. The impact of the consumer awareness program was also significant in driving the manufacturers and consumers towards labeled appliances during the voluntary phase.

This paper describes the methodology and data required in undertaking both the assessment of energy efficiency awareness of manufacturers, retailers and consumers and the impact of the voluntary labeling program in terms of energy savings, CO_2 emission reduction and avoided capacity. The paper presents the results of analysis for both research and report on the main findings and lessons learned.

Introduction

India is currently the 5th largest electricity consumer in the world. The total annual electricity consumption in 2008 was around 601 Billion kWh while the consumption per capita [1] was 526 kWh. Considering the rapid economic growth of the country, the Indian Government set, in its 11th five year plan (2007-2012), an ambitious target of electrification rate and electricity supply. Based on the estimate made at that time, there is a need to increase the electricity generation, which was 159 GW in 2007, by 79 GW by 2012 [1].

The need to increase electricity generation in India is necessary for the country's development. But at the same time, this will lead to an increase of the Indian GHG emissions because thermal power plants still contribute to nearly 80% of the electricity supply [1] and coal fired power plants alone account for nearly 70% of the power generation. Therefore, the Indian Government includes energy efficiency in its energy policy package to reduce its power generation needs and GHG emissions.

To achieve this objective, the Indian Government introduced, in 2001, the Energy Conservation (EC) Act and created the Bureau of Energy Efficiency (BEE) as a statutory body to implement it. In 2006, the Bureau of Energy Efficiency, BEE, implemented a voluntary Star Rating comparative energy labeling program for domestic refrigerators and room air conditioners. The voluntary labeling program started with Frost free refrigerators and tubular fluorescent lamps (TFLs) in May 2006. More products (Direct cool refrigerators, Electric Motors, Air-conditioners and Ceiling fans) were added under the program in 2007. Initially, the labeling program was voluntary but has gradually been made mandatory for some appliances. Currently, the labeling program covers the frost-free refrigerators, room air conditioners, tubular fluorescent lamps and distribution transformers under the mandatory scheme. Direct cool refrigerators, ceiling fans, general purpose industrial motors, monoset pumps, openwell pump sets, submersible pump sets, color televisions (CTVs), washing machines, domestic gas stoves and stationary storage type water heaters (geysers) are covered under the voluntary scheme. BEE decides the labeling criteria after discussion with the main stakeholders. The criteria and energy efficiency performance for different star labels are available on BEE portal under different schedules [7] for different products. The labeling program is not a self-certification activity by the manufacturer. The BEE oversees the labeling program and conducts check-testing to verify manufacturer's claim, done by independent third party verification agencies. The product models are tested in independent facilities. Other manufacturers and users can also challenge the information on the label. BEE is also the enforcing body for products under the mandatory scheme. All the manufacturers participating in the program are required to display the labels.

In order to ensure a successful implementation of the voluntary labeling program for domestic refrigerators and room air conditioners, BEE conducted an intensive communication campaign to raise energy efficiency awareness among consumers, manufacturers and retailers throughout the country.

The labeling programme has generated a significant traction in the market. Labeled products accounted for 11.9% and 26.2% of total room air conditioners sold in 2007 and 2008 respectively. Labeled refrigerators accounted for 32.8% and 83.4% of the total sales for the same period.

With support from USAID, ClimateWorks Foundation, CLASP and LBNL, BEE commissioned a study to analyze the impact of the voluntary labeling program, from energy, environment, and cost-benefit perspectives, for the consumers as well as for the country. The impact assessment analysis showed energy savings of 895 GWh, resulting in 0.70 Mt CO_2 eq. emission reductions and 629.2 MW avoided capacity. Based on the analysis, the impact of the consumer awareness program was significant in driving manufacturers and consumers towards labeled appliances during the voluntary phase.

This paper describes the methodology and data required in undertaking both the assessment of energy efficiency awareness of manufacturers, retailers and consumers and the impact of the voluntary labeling program in terms of energy savings, CO2 emission reduction and avoided capacity. The paper presents the results of the analysis for both research and report on the main findings and draws recommendations.

Assessment of energy efficiency awareness

In this section we present the study conducted to assess energy efficiency awareness of consumers, retailers and manufacturers. The main objective of the study was to analyze and document the impact of the voluntary energy labeling for refrigerators and air conditioners on increasing energy efficiency awareness of manufacturers, retailers and consumers. The 2nd objective was to create a replicable model for impact assessment analysis that can be applied to other labeled products (e.g., tubular florescent lamps, ceiling fans, electric geysers etc.) in India [2].

Methodology

The study proceeded through a detailed market survey of consumers, retailers and manufacturers.

Customers considered for the study are those who had purchased within the year or were planning to purchase a refrigerator or an air conditioner and were the key decision makers in the purchase process. Questionnaire surveys as well as Focused Group Discussions, FGD, were conducted to understand current attitudes and practices with respect to choose an energy efficient product.

A pan-India sample was constructed with due representation to big and small cities as well as rural areas. Four geographical zones (North, South, East and West) were assumed for the country. One mega city, one metro city (population>1 Million), one small town (population < 0.5 Million) and four villages were selected on a random basis.

The sample sizes were determined to assess awareness of the labelling program at 95% confidence level with an acceptable margin error of 5%. Further, to ensure that accuracy should be maintained across bigger as well as smaller cities separately in each region, a total of 400 consumer interviews were targeted. A higher margin error of up to 10% was acceptable in rural areas as the overall awareness is likely to be low hence a sample size of 60 interviews was taken for the rural areas. In total, there were 3,600 listing interviews and 2,000 main interviews with customers, in addition to 6 FGDs each for male and female group across locations. Total interviews conducted were 4776 with 2020 recent buyers.

Regarding retailers, only those dealing in direct retail sales of refrigerators and air conditioners have been interviewed (120 interviews) to understand their views of the voluntary labelling program, the way they communicate to consumers the benefits of buying labelled products as well as the impact of the label on the sales and the challenges they have been facing in promoting labelled products.

Thirty-six manufacturers of refrigerators and air conditioners have also been interviewed with a specific focus on the initiatives and the additional investments they have taken to produce more efficient appliances. The impact of the label on the current sales trends, their perception of the star label at their end and challenges in implementing the voluntary labelling program have also been discussed with the manufacturers.

Key findings

Promotional activities including aggressive campaigning through print and electronic media and awareness and training program for consumers, retailers and manufacturers have been conducted by BEE. The analyses showed that a majority of the Indian population is responsive towards the idea of energy conservation. However, the penetration of information about the star label is still quite low. Over the 4776 respondents, only 19% were aware about the star label [Figure1]. But when considering new purchasers only, 89% of the respondents claim they have considered the information on the label before purchasing a refrigerator and 76% considered the information before purchasing air conditioners [2]. There is also a discrepancy about the awareness of the label between rural and urban areas as well as between regions; the Northern and Western regions seems to be the two regions with less awareness, [Figures 1&2]. 85% of the new purchasers interpret star labels correctly and know that a 5 star product is most efficient. Two years after the launch of the voluntary label, 89% of the consumers associate the label with saving electricity. This is a big progress compared to the 32% during the design phase of the label. The increase of the awareness about the label might be explained by the communication campaigns run by BEE about electricity savings. However the money-saving message conveyed from the label has a much smaller diffusion rate, 7%. The impact of the advertisement campaign run by BEE has been instrumental in making people aware about the program but the influence is limited to major cities. Consumers are aware about the superior quality of labelled products but still consider them expensive when compared to unlabeled ones. Trust levels with the program are very high since it is seen as non-partisan as it’s implemented by BEE– the program is believed to promote a useful concept for the country, not a product or a brand. The Star labeling program is perceived as a Governmental program implemented equally among manufacturers.

Retailers have shown a satisfactory level of knowledge about the intention of the labelling program - about 98% of the retailers felt the star label has an added value for products. The awareness of the star label amongst retailers has been assessed by asking them to explain the meaning of star labelling. More than 70% of retailers were able to identify star labelling with electricity saving and 22% of them were able to mention that more stars indicate more energy saving possibility. Five percent of the retailers identified it with advanced technology and about 13% of them believed the quality of star rated products is better. Labelled products are clearly considered better than unlabeled products on all dimensions except price [Figure 4]. However, retailers have not been pushing the customers into buying labelled products. Regarding the impact of the label on the sales, most retailers state that sales have improved after the introduction of star labelled products with more than 1/3rd of the retailers confirming a significant improvement in refrigerator sales as against about 1/4th of the retailers confirming a significant improvement in AC sales. The difference of the sales increase between ACs and refrigerators might be explained by the high cost difference for AC labelled products compared to the non-labelled ones, while for refrigerators the cost difference is lower.

Retailers were also asked about their understanding of customers’ satisfaction from star-labelled products, based on their interaction with consumers. Nearly 71 % of them stated that customers were ‘very satisfied’ while 26% of them said that consumers were ‘somewhat satisfied. The remaining 3% stated that consumers were neither satisfied nor dissatisfied. There was no mention of consumers being ‘dissatisfied’.

From manufacturers' side, the labelling program is perceived as a marketing tool that allows distinguishing between different brands. This might explain the heavy investments in making their products more energy efficient and hence in achieving higher star rating. Most manufacturers stated that the impact of the program has been positive on overall sales. While some consider the label contribute directly to increase sales, others mention that it has become a talking point that is indirectly driving sales. A few also voiced that there has been no significant impact on sales as the program is in its fledgling stage. The effect on margins was varied across manufacturers. Most manufacturers claimed they had reduced their margins for efficient products in the sensitive price bands.

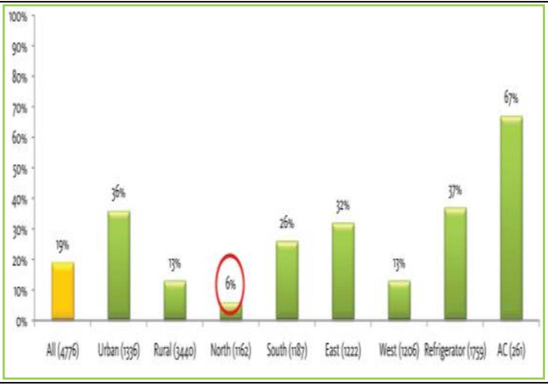


Figure 1: Awareness of star label

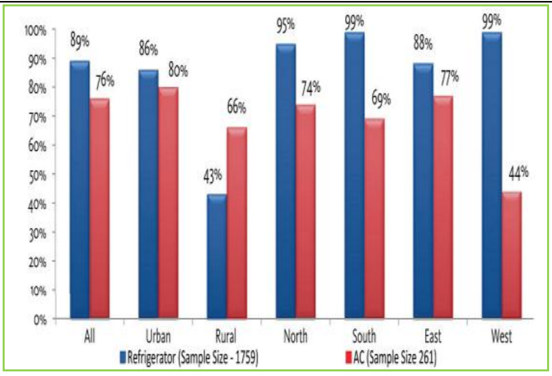


Figure 2: Awareness of star label by new purchasers

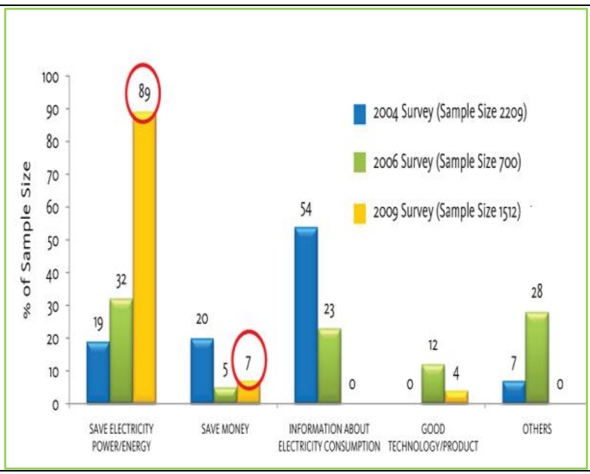


Figure 3 : Awareness level before and after implementing the voluntary label

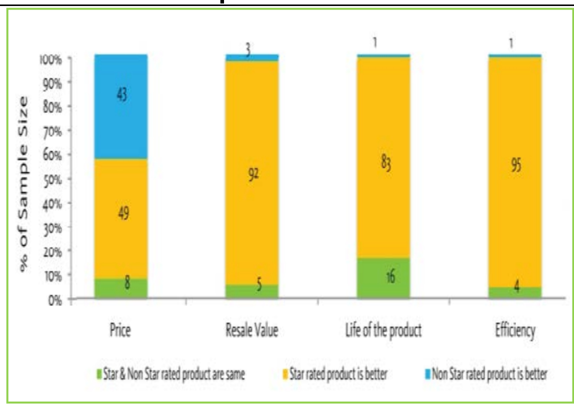


Figure 4 : Retailers' perception of labelled products

Impact of the voluntary labeling program on the sales

In this section, we analyze production and sales of labeled products to establish energy efficiency trends for ACs and refrigerators. The sales and production data used in the analysis are provided by the manufacturers to BEE as part of the agreement for the labeling program under which manufacturers are expected to share their quarterly/half year sales and production data of labeled products with BEE. Manufacturers provided sales and production data for individual models. The country level data has been found after aggregating the data individually for all the models and for all the manufacturers participating in the programme

Based on the data collected by BEE, Table 1, it appears that in 2008, 99% of the registered models for refrigerators and 34% of the registered models for ACs were labeled 3 or more stars. Similar figures for 2007 were 97% and 30% respectively for Refrigerators and ACs. These numbers may yield misleading inferences, showing that the energy efficiency levels are much higher for refrigerators than for air conditioners while this may not be so in reality. The reason is that for easy acceptability, initially the star labeling program for refrigerators was designed to incorporate most of the products available in the market within the labeling scheme. This is the reason why the average market efficiency levels in case of refrigerators are close to 4 star and approximately 99% of the labeled products are 3 stars or above. In case of air conditioners, before the launch of the labeling program, the market had very poor average efficiency levels. Thus in the initial phase of the labeling program the average efficiency in terms of rating was somewhere between 1-2 Star. This is the reason why only 34% of the labeled products are 3 Star and above. BEE has already started working towards making the energy efficiency criteria for labeling more stringent over the next few years and with this, the efficiency levels are expected to improve considerably.

From market share perspective, sales of labeled products have been analyzed to get an understanding of the market penetration of labeled products. The analysis showed a healthy increase for both refrigerators and ACs. Labeled refrigerators comprised 83% of the total refrigerator market in 2008 (where as in 2007 this figure was 33%) and likewise 26% of the AC market comprised of the labeled products in 2008 (in comparison to 12% in 2007), Table 2. The regional sales of labeled products are mostly dominated by the urban market comprising of 73% for refrigerators and 84% for ACs. The zone-wise segmentation of sales figures for labeled products is more or less even between the northern, southern and western zones. However the share is very less for eastern zone primarily because of the climatic conditions and also uneven population distribution. Considering the magnitude and spread that the program has been able to achieve across India, cultural differences between North, South, East and West zones and different nuances to operating cost and money saving across different zones need to be explored and capitalized upon as the communication objective in the near future. Use of local language for promoting the program in the rural regions is strongly recommended.

	Refrigerators				**AC**			
	2007		2008		2007		2008	
	Number of registered models	Number of models sold	Number of registered models	Number of models sold	Number of registered models	Number of models sold	Number of registered models	Number of models sold
Star1	0	0	0	0	47	14	61	11
Star 2	7	2	4	2	62	20	167	47
Star 3	71	23	107	29	19	2	26	9
Star 4	194	116	361	228	17	5	26	9
Star 5	8	4	43	14	11	6	38	5

Table 1: Number of models registered for labeling and number of models sold

	Refrigerators		**AC**	
	2007	2008	2007	2008
Star1	0	0	31.148	94.988
Star 2	3.035	4.659	196.682	370.531
Star 3	199.535	546.739	8.002	162.848
Star 4	1.369.525	3.050.064	10.539	21.823
Star 5	4.411	986.574	3.730	5.937

Table 2: Annual sales of labeled products

Assessment of energy savings and GHG emission reduction

In this section, we present the analysis we conducted to quantify the energy savings and GHG emission reduction by implementing a voluntary labeling program for refrigerators and ACs.

Methodology and main assumptions

- For refrigerators, the star rating band is based on the storage volume and the annual energy consumption consumed by the model of same volume. The details on the energy consumption and awarded star label based on tested energy performance are available under different schedules for different products on BEE's web portal [8]. The schedules have been used for energy and GHG saving calculations

The annual Energy Savings are calculated using the formula below:

$$\text{Energy savings (KWh)} = \sum \text{Energy Savings}_{\text{unit wise}} \text{ (for all the units sold)}$$

where

- Energy Savings $_{\text{unit-wise}}$ = {Energy$_{\text{unlabeled}}$ - Energy[1]$_{\text{labeled}}$}
- Energy$_{\text{unlabeled}}$ = Energy consumption by 3 Star product of same storage volume (adjusted volume)

Based on the market share analysis presented above, we considered Star 3 as a baseline as the average market efficiency. The K_{nf} and C_{nf} parameters used are respectively 0.413 and 346 for direct cool refrigerators and 0.5578 and 486 for Frost free refrigerators [3].

- For ACs, the rating is based on EER (energy efficiency ratio). The averaged value of EER for the AC market is found to be 2.2 (slightly lower than a 1 Star AC for which EER is 2.3)

  EER is calculated by dividing the cooling capacity by power consumption. Baseline energy consumption is for a product with same cooling capacity and $EER_{unlabeled}$ = 2.2.

  - Power savings = {Cooling Capacity (W)/$EER_{unlabeled}$ – Power Consumption$_{\text{labeled}}$ (W)} * Number of units sold
  - Total power saving = ∑ power saving $_{\text{all units sold}}$
  - Annual Energy Savings (in kWh) = Power Savings * no. of days of operation in a year * no. of hours of operation in a day
  - We assumed that AC works for 150 days per year and 8 hours per day.

- GHG abatement has been calculated using the formula below:

$$GHG_{mitigated} = \sum E_{savings} * GHG_f$$

  - $GHG_{mitigated}$ – total reduction in the greenhouse gas emissions in tons of CO_2 equivalent
  - $E_{savings}$ – zone wise energy savings in MWh
  - GHG_f – GHG emitted for a unit production of electricity in a particular grid zone are available, in tons of CO_2/MWh. The Central Electricity Authority (CEA) of India publishes the CO_2 baseline data for the four zones of the country [5]. The weighted average emission rate for year 2006-07 and 2007-08 for North/East/West zone was 0.82 and 0.81 respectively. For south India, the weighted average emission rate was 0.72 for these years.

- The avoided capacity is the reduction of the power demand at the production stage due to the use of more efficient products. However, since India already has power deficit, the avoided capacity from such energy efficiency programs does not exactly translate into capacity reduction of power plants but helps in meeting the deficit to some extent.

[1] Energy$_{\text{labeled}}$ is actual energy consumption obtained from laboratory test data provided by the manufacturers

The avoided capacity has been calculated using the formula:

$$\text{Avoided Capacity} = \text{Total power savings} / \{\text{Capacity factor}^{2} * (1 - \text{T\&D}_{\text{losses}}{}^{3})\}$$

Considering the following assumptions:

- Capacity factor of 80% [5]
- Transmission and distribution (T&D) losses of 27% [5] (The difference in the power generated and delivered is because of the losses occurring during transmission and distribution)

Key findings

Based on the methodology described and the assumptions considered above, the average energy savings for each model of refrigerators has increased in 2008 over 2007 for all the star ratings with the exception of 5 Star products with lesser storage volume (< 200 liters) due to low penetration to the Indian market of lesser storage volume. The total energy savings achieved from the refrigerators voluntary labeling program in 2008 was 526 GWh compared to 217 GWh in 2007. Regarding air conditioners, the estimate of the energy savings due to the voluntary labeling program of ACs is 369 GWh in 2008. This is nearly three times the savings achieved in 2007 (117 GWh). An interesting trend emerges from the analysis, the total energy savings from the window AC units has doubled from 2007 to 2008 while from split AC units it has increased close to 5 times in the same period. There are two reasons for this - the sale of labeled split ACs with high star rating (3 Star and above) has been more in comparison to window ACs and also the energy savings achieved from split ACs is more than the window ACs for same capacity and star rating (as the power input of window unit is more than the one needed for split unit for the same EER). The average energy savings for most AC in various star bands for 2007 are marginally more than those for 2008. The number of labeled models sold in 2008 is high compared to those sold in 2007, Table 1.

The estimate of the cumulative mitigation for the 2 years of implementation of the voluntary program for both refrigerators and ACs is 0.7 Mt CO_2 eq. and the total avoided capacity due to the voluntary program was 629.2 MW in 2008 as compared to 207.5 MW in 2007. The avoided capacity evaluated is significant in the context of India's power scenario. Currently, India has a power deficit of close to 70.000 MW [6], the avoided capacity from the star rated refrigerators and ACs is capable of addressing 1.2% of the deficit. This share should have increased since the labeling program became mandatory in 2010 and more products are included in the voluntary program. The avoided capacity from S&L program is expected to make a much more pronounced impact in overcoming the power deficiency of India.

	Refrigerators		ACs	
	2007	2008	2007	2008
Total energy savings (GWh)	217	526	116	369
GHG abatement (Mt CO_2 eq.)	0.18	0.4	0.09	0.29
Avoided Capacity (MW)	42.3	102.8	165.2	526.4

Table 3: Energy savings, GHG abatement and avoided capacity due to Refrigerators and ACs voluntary labeling program

Cost-benefit analysis

In this section, we present the cost benefit analysis we conducted both at the country and consumer level.

Methodology and main assumptions

- Cost benefit at the country level has been calculated using the cost benefit ratio methodology as described below:

[2] capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time and its output if it had operated at full capacity the entire time

[3] T&Dloss is the difference in the power generated and delivered is because of the losses occurring during transmission and distribution

$$\text{Cost benefit ratio} = AC^* C_{plant} / C_{program}$$

where

- AC is the avoided Capacity in MW
- C_{plant} the cost of establishing new facilities for the unit demand.
- $C_{program}$ – total cost of the labeling program.

We assumed:

- The cost of establishing new power plant to be NR[4] 40 Million/MW [5]
- BEEs' estimate for the total cost of voluntary labeling program (INR 5.25 Billion[5])

- From consumers' perspective, the cost benefit is based on the payback period, cost benefit ratio and life cycle cost, LCC, have been considered in the analysis of the impact of the voluntary labeling program.
    - The payback period has been calculated using the formula below:

$$\text{Payback Period}^6 = C_{additional} / (E_{sp}{}^* U_{rate})$$

where

- $C_{additional}$ – extra cost of the product for consumer
- E_{sp} – energy saved by the product annually
- U_{rate} – tariff on per unit electricity consumption

    - The cost benefit ratio has been calculated using the formula below:

$$\text{Cost benefit Ratio} = \text{Total money saved / extra cost incurred} = (E_{sp}{}^* U_{rate}{}^* L) / C_{additional}$$

where

- Esp – energy saved by the product annually in kWh/year
- Urate – tariff on per unit electricity consumption (INR/kWh)
- $C_{additional}$ – extra cost of the product (extra cost borne by the consumer because of the cost incurred for achieving energy efficiency in the product) in INR
- L – average life time of the product in years

    - And LCC has been calculated as follows:

$$LCC = P + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

where

- *LCC* – Life cycle cost in INR

---

4 INR: Indian Rupees

5 Calculated Based on interviews with Manufacturers and BEE

6 Simple payback period considered as per BEE's request because easier to communicate to consumers

- *P* – additional price of labeled product over the unlabeled one in INR
- *OC* – Operating cost of the products (here the operating costs are negative as it is mainly electricity savings by virtue of using the product) in INR

OC = Annual Savings (in kWh) * Tariff per unit (INR/kWh)

- *L* – average lifetime of the product in years
- *DR* – Annual discount rate (in % for accommodating for time value of money)

we assumed:

- Life cycle of both refrigerators and ACs is assumed to be 10 years
- Tariff on per unit (kWh) electricity is assumed to be 4 INR and is assumed to be stable for during product's lifecycle.
- Maintenance and repair cost difference due to owning an efficient product have been ignored
- The rate of discount = 9%

Key findings

At the country level, the analysis showed a cost benefit ratio of 48 considering a total avoided capacity of 629.2 MW, Table 4, in 2008. This indicates that the program is highly beneficial and the national benefits arising out of the S&L program heavily out-weighs the expenditures. In this way, the Indian experience is comparable to the experience in other countries, showing that standards and labeling is among the most cost effective programs in terms of government investment in direct program costs.

From the consumers' perspective, the payback period when buying a 4 Star refrigerator is less than 2 years and the cost benefit ratio is 5.6. For Air-conditioners, the payback period when buying a 2 Star AC is 1.6 and the cost benefit ratio is 6.7. The LCC analysis showed negative values which means consumers are in fact saving money by opting for labeled products. These results are again comparable to the experience in other countries, where similar improvements for refrigerators and air conditioners have been shown to be highly cost effective to consumers.

	Refrigerators				ACs			
Star Rating	Additional Cost to consumers (INR)	Payback period (Years)	Cost Benefit Ratio	LCC (INR)	Additional Cost to consumers (INR)	Payback period (Years)	Cost Benefit Ratio	LCC (INR)
1 Star	–	–	–	–	1500	1.5	7.2	-4846
2 Star	–	–	–	–	2700	1.6	6.7	-7108
3 Star	–	–	–	–	4000	2.0	5.0	-8957
4 Star	1000	1.9	5.6	-2038	6000	2.25	4.7	-13628
5 Star	2000	2.3	4.6	-1063	8000	3	3.3	-13287

Table 4: Cost-benefit analysis for purchasing labeled Refrigerators and ACs[7]

Outcomes and Conclusions

The analysis created a framework model to conduct impact assessment of the voluntary labeling program for ACs and refrigerators in India. The framework model is replicable for impact assessment analysis for other labeled products.

[7] The exact 3 star specifications have been used for base lining the refrigerators hence there are no associated benefits reported for refrigerators with a label of 3 stars or less. The baseline for RACs is air conditioners with EER of 2.2 which is slightly weaker than 1 star specifications (EER 2.3 to 2.49) hence related benefits have been reported

The analysis showed regional differences regarding the label awareness of the Indian consumers. Cultural differences between regions and nuances to operating cost and money saving across zones need to be explored and capitalized upon as the communication objective in the near future. Use of local languages in rural areas is recommended.

Refrigerator was one of the first products to be brought under the voluntary labeling program. The criteria were kept less stringent to ensure wider acceptability. The impact of the refrigerators voluntary labelling program is low because the Star labelling program for refrigerators was based on the lowest energy efficient products instead of the average efficiency in the Indian market. The labeling program for subsequent products, for instance, ACs considered average market efficiency. To realize more benefits, it is therefore recommended for the next revision of the labelling program by 2015 and for any new labelling program to consider the average market efficiency.

Based on the analysis, the voluntary labelling program should have saved 895 GWh and 0.70 $MtCO_2$ eq. of GHG emission). By implementing a voluntary labeling program for refrigerators and ACs, BEE has achieved an effective demand reduction of 629.2 MW. This represents approximately 1.2% of the estimated projected national power deficit in India. This share is expected to increase as the labeling program became mandatory in 2010 and also with inclusion of more products in the voluntary program. The avoided capacity from S&L program is expected to make a much more pronounced impact in overcoming the power deficiency of India in coming years

References

[1] EIA statistics on electricity consumption, http://www.eia.doe.gov/cabs/India/Electricity.html

[2] *Impact Assessment for refrigerator and Air conditioner voluntary labeling program in India*, EDS, 2010

[3] Schedule 1 & 4 for future approach in standards and labelling of refrigerators and air conditioners http://220.156.189.23:8080/beeLabel/Schedules/Schedule1-FFR.pdf and http://220.156.189.23:8080/beeLabel/Schedules/Schedule4-DCRefrigerator.pdf

[4] *"Energy End Use" – A Baseline Study Report for residential electrical equipments* – TERI (The Energy and Resource Institute), 2008

[5] Report of Expert Committee on fuels for power generation - Central Electricity Authority - Planning Wing-Feb-2004-. http://cea.nic.in/god/opm/Thermal_Performance_Review/0809/Highlights.pdf

[6]http://timesofindia.indiatimes.com/india/India-facing-70000-MW-power-shortage/articleshow/1974258.cms

[7] http://220.156.189.25:8080/beeLabel/index.jsp

[8] http://220.156.189.25:8080/beeLabel/protected/jsp/SearchOptions.jsp

At the doorstep of the new EU Label – How much further can White Goods cut down on the energy bills?

Anton Eckl, Key Account Manager

GfK Retail and Technology, Nuremberg/Germany

Abstract

This paper looks back at the success of the EU Energy Label over the past decade. But now it is high time for a thorough revision. This look back is followed by an analysis of the first indications on the penetration of the new energy label as of Jan-Feb 2011 and the potential energy savings. A final look is shed on countries around the globe, where a similar revision of the label would be highly recommended. If not stated otherwise, the source of information is proprietary GfK Retail and Technology research findings. i.e. measures of the retail sell-out to final consumers in a particular country, calculations from GfK Retail and Technology's ECO Reporting or own calculations by the author.

The World Market for White Goods

Return to the long-term growth path

GfK Retail and Technology estimates show consecutive world market growth until 2008, the year, when the financial crisis began. 2009 saw a downturn in sales of -6%. Most heavily affected countries besides Great Britain and Spain were the Central Eastern European economies and CIS member states. Global sales are forecast to reach a new all-time-high of 160 bill. US$ in 2010.

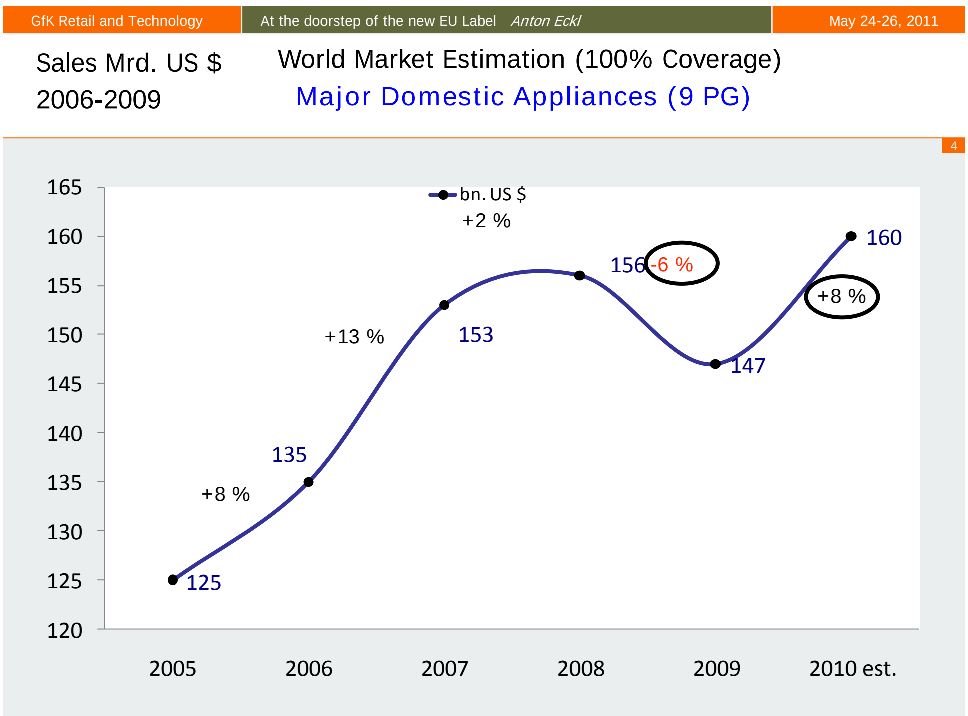


Figure 1: Global White Goods market size and growth rates

Figure source: GfK Retail and Technology World Market Estimation

Europe is the most important sales region for White Goods

Western[1] and Central Eastern Europe (excl. CIS)[2] account for more than one third of the global market for White goods. The biggest single economy however still is the United States followed by China. Given the current double-digit growth momentum of China, China may become the most important single market by 2015.

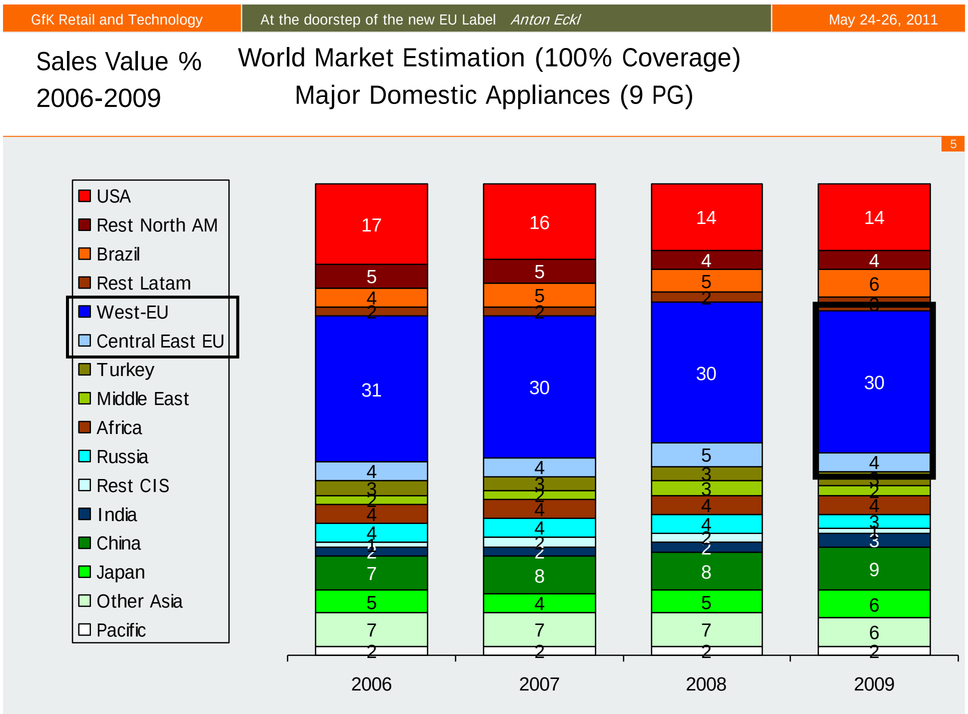


Figure 2: Global White Goods market by regions

Figure source: GfK Retail and Technology World Market Estimation

Household Energy Consumption

An example from Germany shows the high relevance of energy efficiency for White Goods as they account for 50% of the average household's electricity consumption. Cold appliances (refrigerators and freezers) contribute slightly more than Wet (Washing Machines and Tumble Dryers) and Hot appliances (Cookers, Ovens and Hobs) together to the electricity bill.

---

[1] Western Europe = 14 Western EU countries (AT, BE, DE, DK, ES, FI, FR, GB, GR, IE, IT, NL, PT, SE) + Luxemburg, Cyprus, Malta, Norway and Switzerland.

[2] Central Eastern Europe = 10 Eastern EU countries (CZ, SK, HU, PL, SI, RO, BG, EE, LV, LT) + Croatia, Serbia, Bosnia-Herzegovina, Kosovo, Montenegro, Mazedonia, Albania.

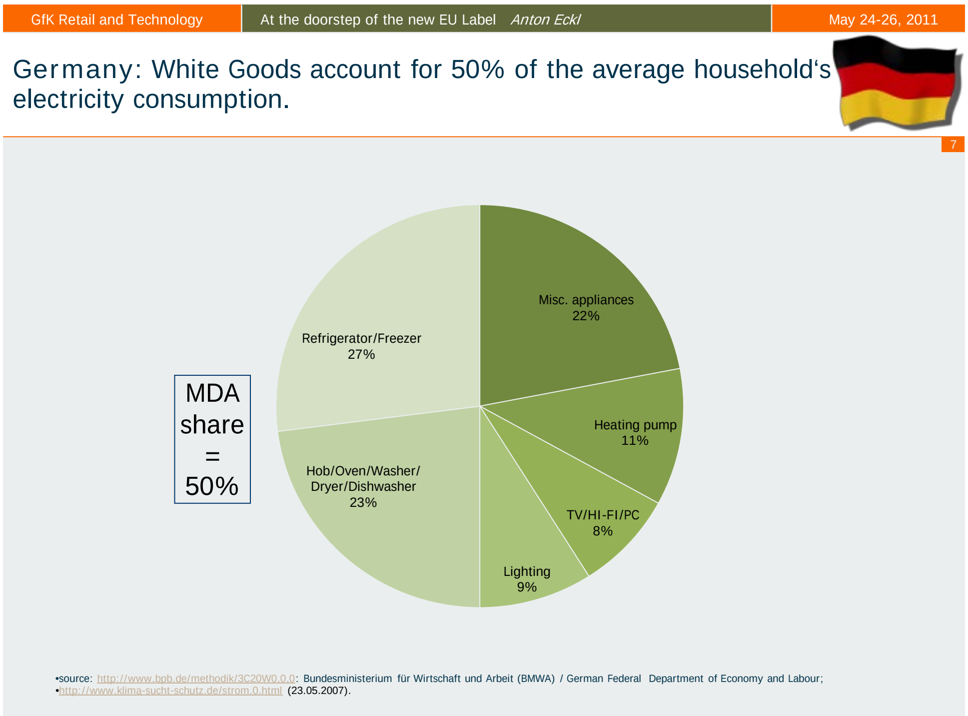


Figure 3: Household energy consumption pattern in Germany

Figure source: http://www.bpb.de/methodik/3C20W0,0,0: Bundesministerium für Wirtschaft und Arbeit (BMWA) / German Federal Department of Economy and Labour; http://www.klima-sucht-schutz.de/strom.0.html (23.05.2007).

The EU Energy Label – a success story

But market transformation process rendered the label meaningless

More than a decade after the introduction of the first label for Cold appliances and its extension to A+ and A++ in 2003, the label became by and large meaningless for Washing Machines and Dishwashers, where the market today is more or less a market of A-label appliances. In Cold appliances A++ appliances account for almost 8% of sales, 40% of the sales stem from A+ appliances.

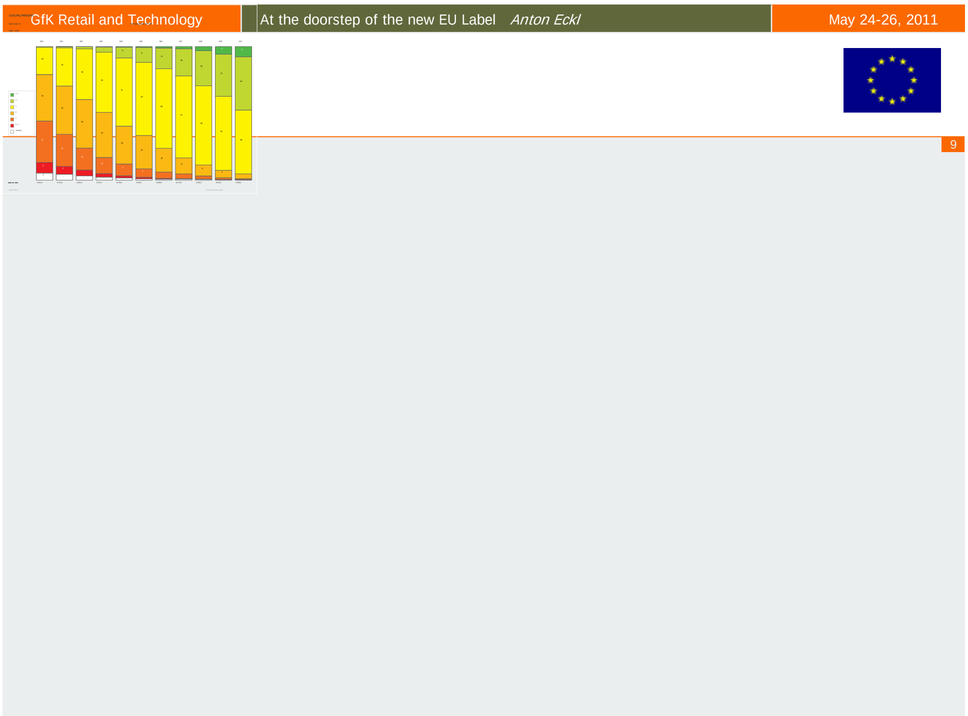


Figure 4: Sales share of Energy Efficiency classes for Cold appliances in 10 Western EU countries[3]

Figure source: GfK Retail and Technology Retail Audits

Mid-term impact of better Energy Efficiency on the average consumption of new appliances

The average consumption index reflects very well the efforts of the industry to offer more and more efficient appliances and the willingness of the European consumers to buy them. This index fell from 2005 to 2010 from 100 to 93 (dishwashers) respectively 86 (freezers) (see fig. 4). In other words: the average appliance sold in 2010 uses up to 14% less energy compared to 2005. Improved energy efficiency over-compensated the parallel trends towards the more convenient but also more energy-consuming Nofrost technology (see figure 6) as well as the trend towards bigger appliances in general . Only in washing machines we see a reversal of the consumption index starting in 2008 because of the growing demand for bigger drum sizes across Europe (see figure 7).

[3] 10 Western EU countries = AT, BE, DE, ES, FR, GB, IT, NL, PT, SE

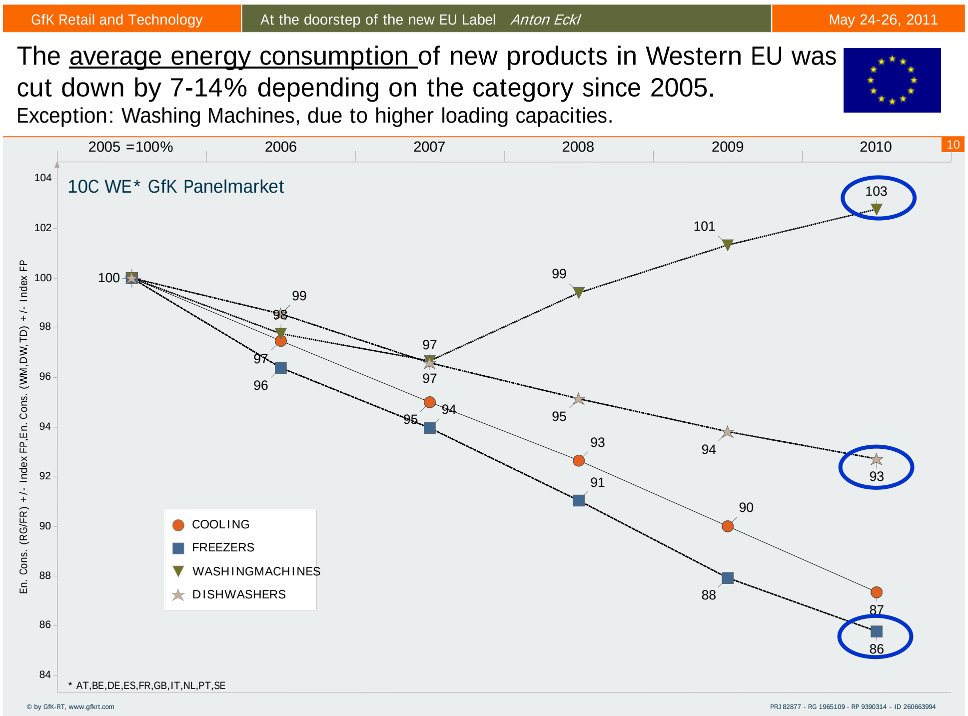


Figure 5: Sales-weighted average energy consumption index in 10 Western EU countries

Figure source: GfK Retail and Technology Retail Audits and ECO Reporting calculations

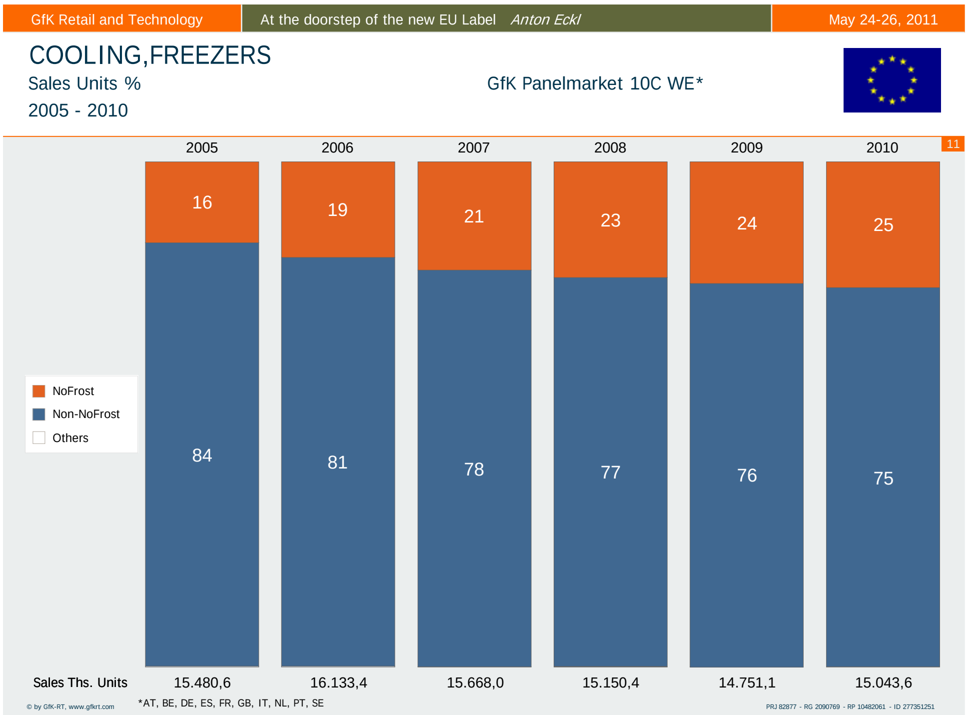


Figure 6: Sales shares of Cold appliances with NoFrost technology in 10 Western EU countries 2005-2010

Figure source: GfK Retail and Technology Retail Audits

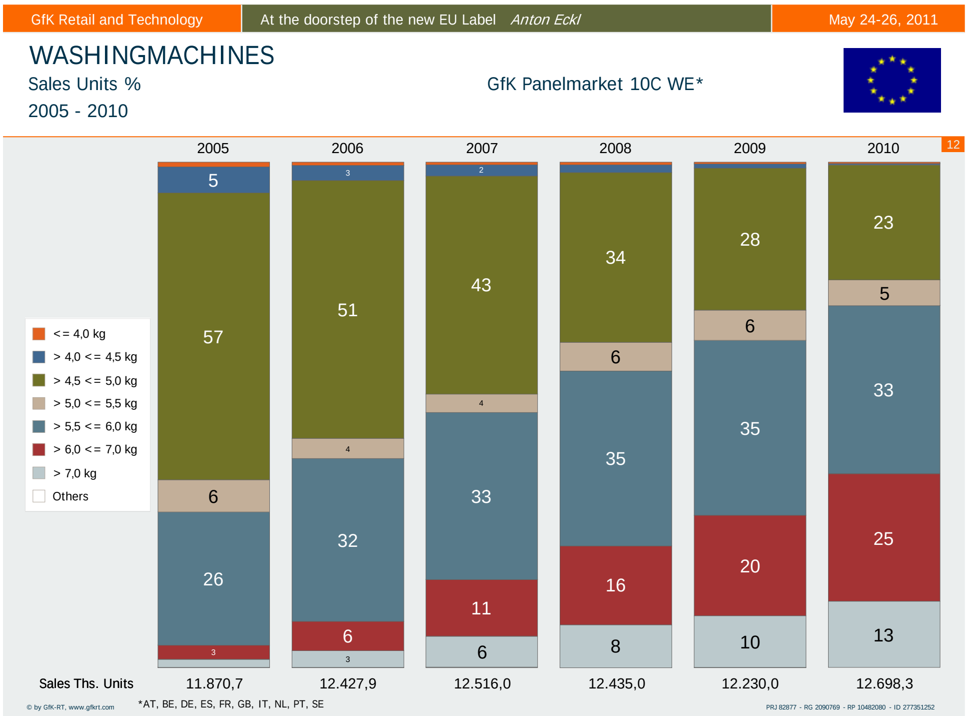


Figure 7: Sales shares of Washing Machines by loading capacity in 10 Western EU countries 2005-2010

Figure source: GfK Retail and Technology Retail Audits

Regional differences in energy consumption levels remain, but became smaller from 2005 to 2010

The average new appliances' annual energy consumption in kWh is calculated as the sales-weighted average of 4 major domestic appliances, namely washing machines, dishwashers, cooling/refrigerators and freezers. The annual consumption for Cold appliances is taken from the Energy Label. In the case of washing machines and dishwashers the per-cycle values are taken from the label. Annual values are calculated from that by applying usage assumption as follows: 220 loads for washing machines and 280 loads for dishwashers. These are also the reference values for the new energy label.

GfK data suggests that Germany is the Energy Efficiency champion in Europe when it comes to White Goods. But other countries are on a good way. Spain exhibits the highest efficiency gains, not the least thanks to the Plane Renové program that has been running since 2006. Also the Italian subsidy program for Cold appliances (2007) showed a positive impact as did the Austrian 'Trennungspraemie' (scrapping bonus for White Goods) in 2009 and 2010 show a positive impact. All of these countries show a double-digit decrease in average energy consumption over the last 5 years' period.

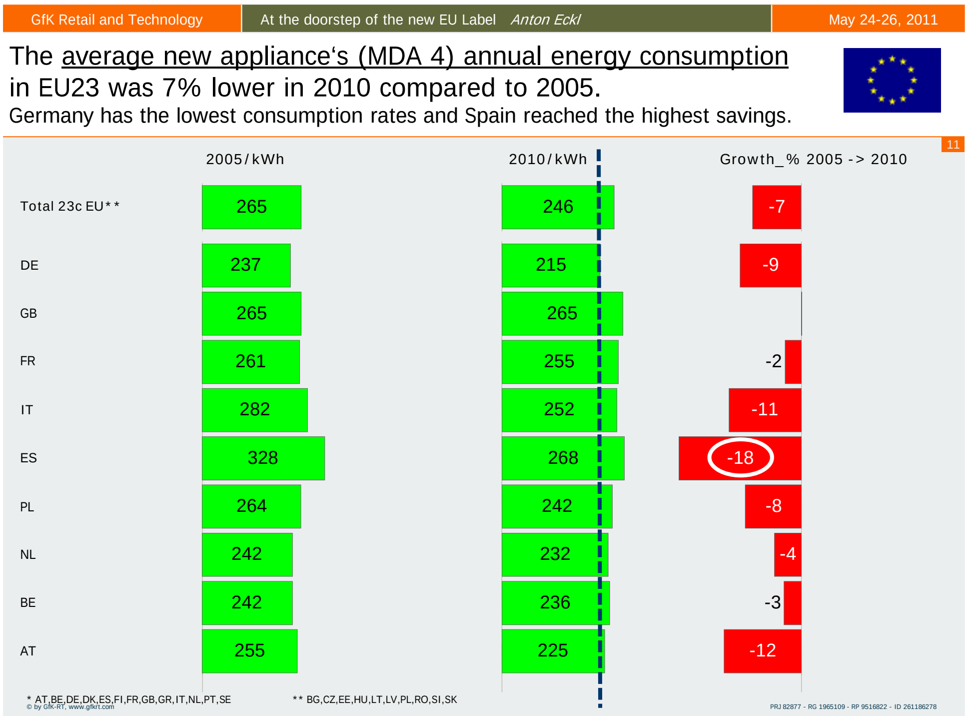


Figure 8: Sales-weighted average energy consumption (MDA 4) in major EU markets

Figure source: GfK Retail and Technology Retail Audits and ECO Reporting calculations

Case Study Germany: The total annual fleet consumption of new products went down by 15% from 2000 to 2010

GfK' ECO Reporting calculations suggest that the annual fleet consumption (=cumulative annual electricity demand of all appliances sold in a particular year) that this figure could be significantly reduced albeit the increasing popularity of convenience features (e.g. larger capacities, No Frost) coincide with a higher energy consumption per appliance.

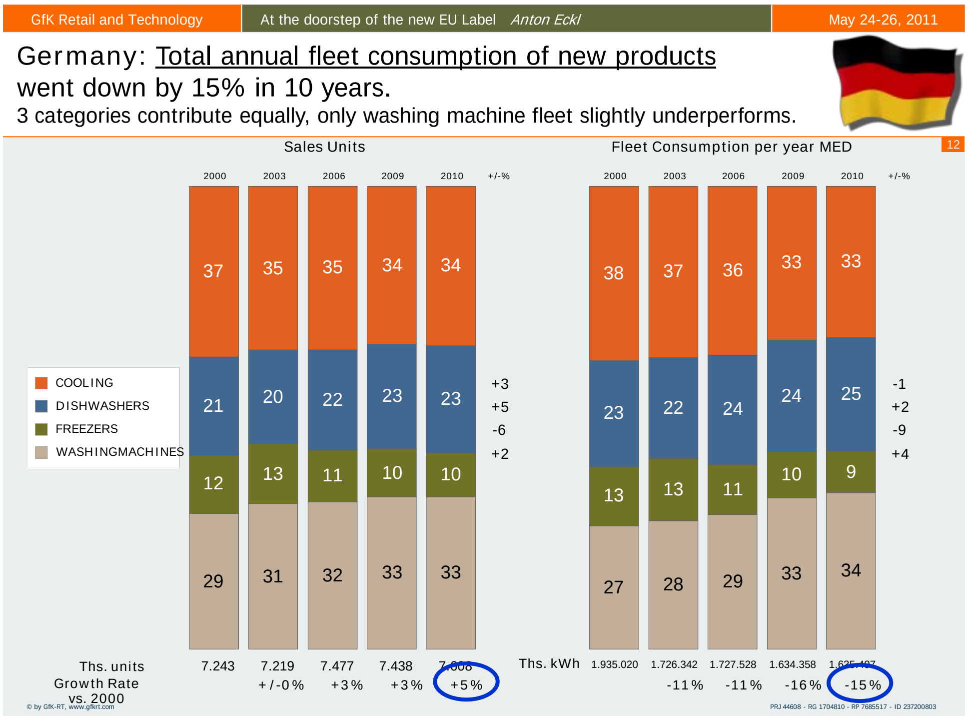


Figure 9: Total annual fleet consumption of new products (MDA 4) in Germany 2000-2010

Figure source: GfK Retail and Technology Retail Audits and ECO Reporting calculations

Forecast savings 2000-2020 for Germany amount to 24% of electricity demand for new White Goods products

The average lifetime of major domestic appliances in a household varies from 12 years for washing machines and dishwashers to 15 years for cooling/refrigerators and 17 years for freezers.

In order to get an idea of the magnitude of potential energy savings the following assumptions are made: Appliances are replaced already at an earlier stage in order to benefit from the technological progress in energy consumption. Real savings due to the replacement of older appliances might be between 5 and 10% higher than in the following modeling as the average lifetime stretches from 12 to 17 years as mentioned above. The new energy label introduced in 2011 will increase market transparency in favor of energy saving appliances and most probably pushing supply and demand into that direction. Potentially higher energy savings could be reached.

This forecast is based on GfK Retail and Technology's ECO Reporting calculations for the years 2000-2010 and own calculations based on 2000-2010 Retail Audit data. Market growth is forecast at +0,5% p.a. (average of last 10 years). Energy consumption decrease is forecast at the average rate of the past 5 years (-1,6% p.a.).

GfK Retail and Technology | At the doorstep of the new EU Label *Anton Eckl* | May 24-26, 2011

Germany: Savings potential based on <u>total annual fleet consumption of new products.</u>

MDA 4: Washing Machines, Dishwashers, Cooling/Refrigerators, Freezers

13

	Savings realized 2000 => 2010	Savings forecast 2010 => 2020	Savings forecast 2000 => 2020	Assumptions 2010 => 2020
Germany	-15%*	-10%*	-24% = 162 mill. kWh*	av. market growth last 10 years: +0,5%; av. energy consumption decrease of appliances last 5 years: -1,6%

* approx. equivalent to 2 ½ months the total electricity consumption of Copenhagen's households

*x% of savings calc. on that part of stock, if all 10 year old appliances would be replaced

Figure 10: Savings potential of new products (MDA 4) in Germany 2000-2020

Figure source: GfK Retail and Technology Retail Audits, ECO Reporting and own calculations

The new EU Energy Label after revision

The new energy label for washing machines, dishwashers, cooling and freezers is released for voluntary use since December 2010. It will become compulsory at the end of 2011. GfK can already now report on its market penetration. It was high time for the arrival of the new label for washing machines and dishwashers as virtually the whole market was already classified as A according to the old label. Manufacturers used a so-called super-declaration (e.g. 10% more energy-efficient than the benchmark for A = 0,19 kWh/kg) to differentiate their most efficient appliances.

According to the new label already 4% of all washing machines sold in Western Europe in Jan-Feb 2011 were qualifying for A+++, 3% for A++ and 8% for A+ compared to 4% of A+ in dishwashers. 6% of all dishwashers were rated A++. A+++ dishwashers accounted for around 1%.

For cold appliances A+++ was added to the scale. While no sales for A+++ fridges could be reported, there were already around 1% of sales registered for A+++ freezers (mainly upright freezers with Nofrost and chest freezers).

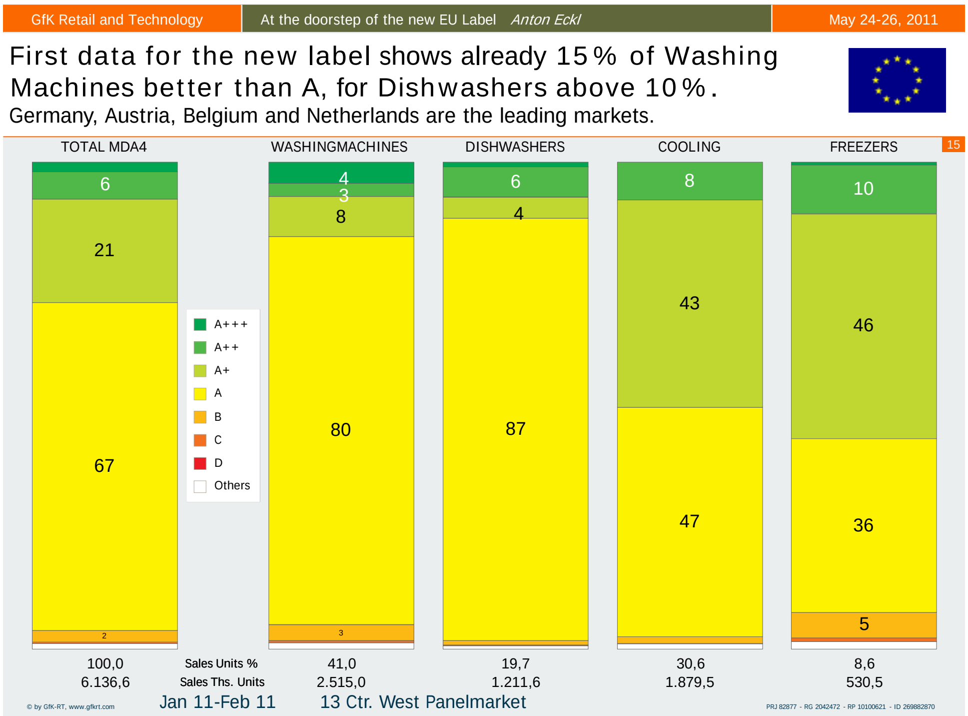


Figure 11: Sales share (units based) of A+++ appliances in 13 Western EU countries Jan-Feb 2011

Figure source: GfK Retail and Technology Retail Audits

The current price premium for Upright >90cm Nofrost A+++ freezers is at 60% over a comparable A++ appliance, which is higher than in the case of washing machines (54%) and dishwashers (14%). Nevertheless consumers can get the best available technology basically at the same price (inflation considered) as in 2000, when the best available technology was A.

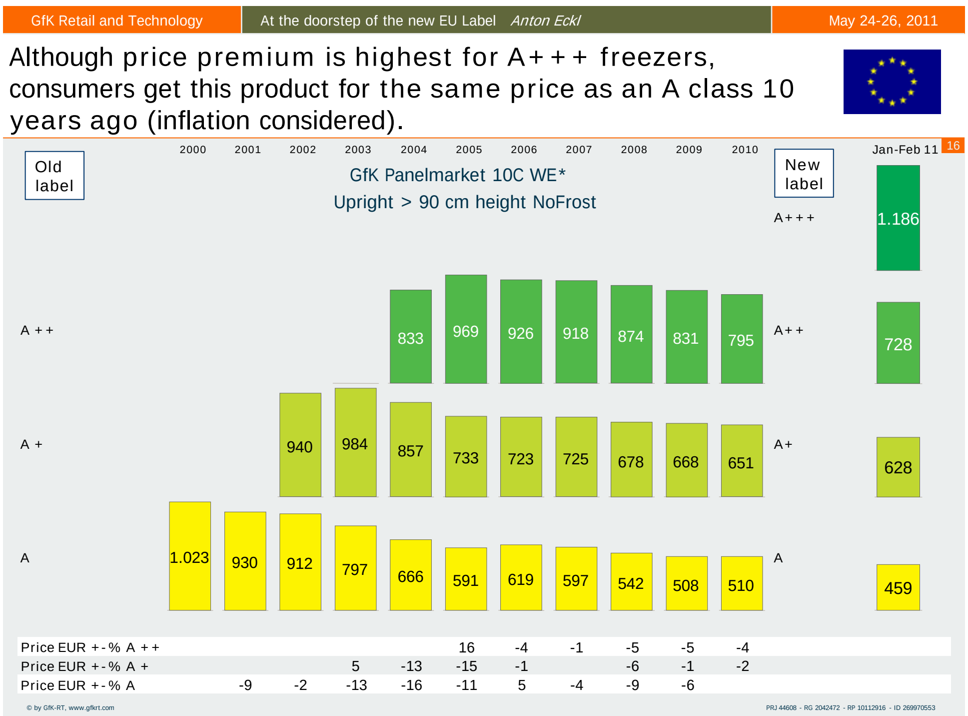


Figure 12: Average sales price of Upright >90cm height NoFrost appliances 2000 - Jan-Feb 2011

Figure source: GfK Retail and Technology Retail Audits

Can subsidies boost the sales of A+++ Cold appliances?

Given that currently high price premium, policy makers could consider a subsidy of the one or the other form in order to boost sales of A+++ fridges and freezers at an early stage. Various examples from European countries have proven that subsidies can help the sales of highly efficient appliances (e.g. in Spain, Italy and Austria).

Austria offered the so-called ‘Trennungspraemie’, a scrapping bonus for Cold as well as Laundry appliances. Cold appliances were subsidised during two periods, Sep-Dec 2009 and Sep-Nov 2010. Consumers could apply for a reimbursement of up to 100€ for the replacement of an old appliance by a new A++ appliance.

In between Washing Machines and Tumble Dryers were subsidised during April and May 2010. The total budget spent was around 7 mio. Euros.

The Austrian scrapping bonus for Cold appliances features the unique case of a repeated campaign within a short period of time. During the first campaign not only better appliances were sold, A++ increased to a value share of 30% and 34% in Sep-Oct and Nov-Dec 2009 respectively, but the whole market value could be increased, i.e. a significant proportion of consumers anticipated sales they were planning for the next months in order to benefit from the campaign bonus. The second wave, however, showed only an improvement of the sales structure, i.e. more A++ appliances sold, but the market size even decreased, i.e. early replacement buyers were already triggered by the first wave.

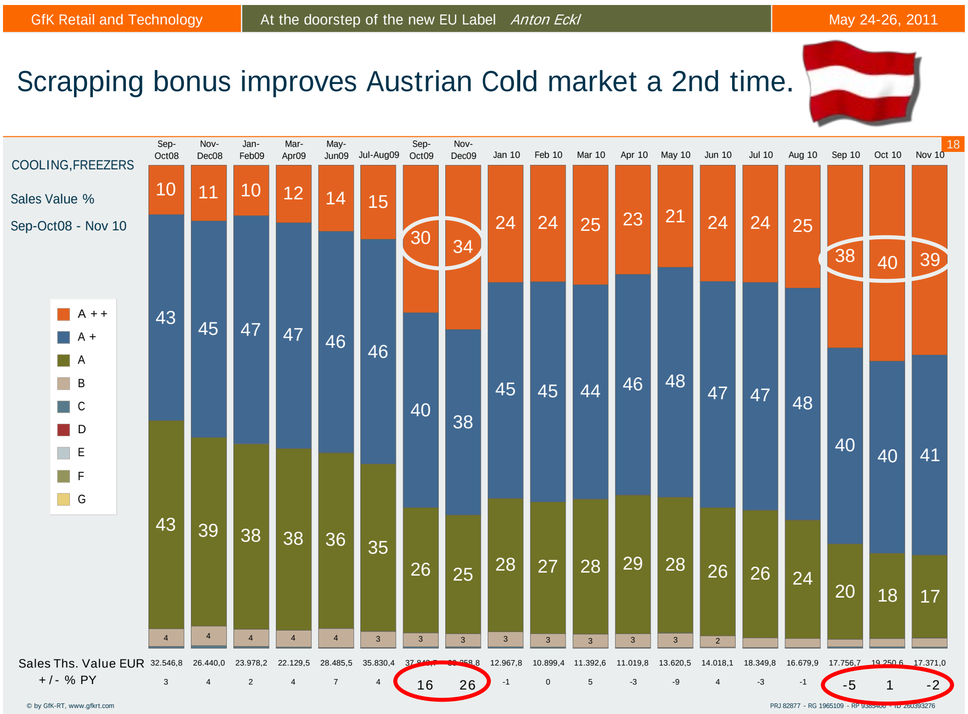


Figure 13: Sales shares (value based) of A++ Cold appliances in Austria 2008-2010

Figure source: GfK Retail and Technology Retail Audits

Energy labeling programs outside Europe with need for revision

The following chapter refers to selected countries with energy labeling schemes where GfK Retail and Technology runs retail audits.

Brazil

The Brazilian Procel Label was introduced in 1993 together with a local adaption of the old EU-label (before the amendment of A+ and A++ in 2003). Although the testing standards are not exactly the same as for the EU-label, the efficiency of the same grades (A, B etc.) would be by and large comparable. It is compulsory for washing machines, cooling/refrigerators and freezers, cookers/ovens as well as air conditioners.

Chile followed with a similar labeling scheme in July 2007, but only for cooling/refrigerators and freezers.

In 2010 A-class refrigerators take up the lion's share of 85% in Brazil, whereas they still represent the minority (35%) of sales in Chile compared to B-class appliances.

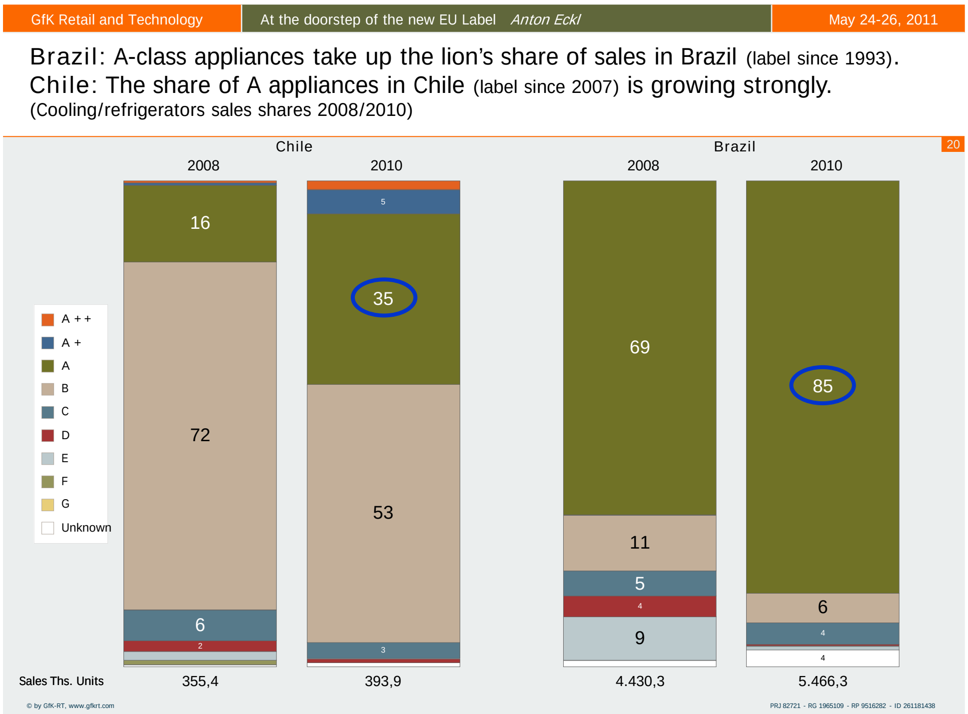


Figure 14: Sales shares for Cooling/refrigerators by Energy Label in Brazil and Argentina 2008/2010

Figure source: GfK Retail and Technology Retail Audits

India

The Indian BEE (Bureau of Energy Efficiency) Label was introduced in March 2002. It follows the Star Rating logic of the Australian label and is compulsory for cooling/refrigerators and freezers as well as air conditioners.

In December 2010 the sales share of 5 Star refrigerators reached 58%, which is 3 percentage points above the 2010 average and suggests that this trend will continue.

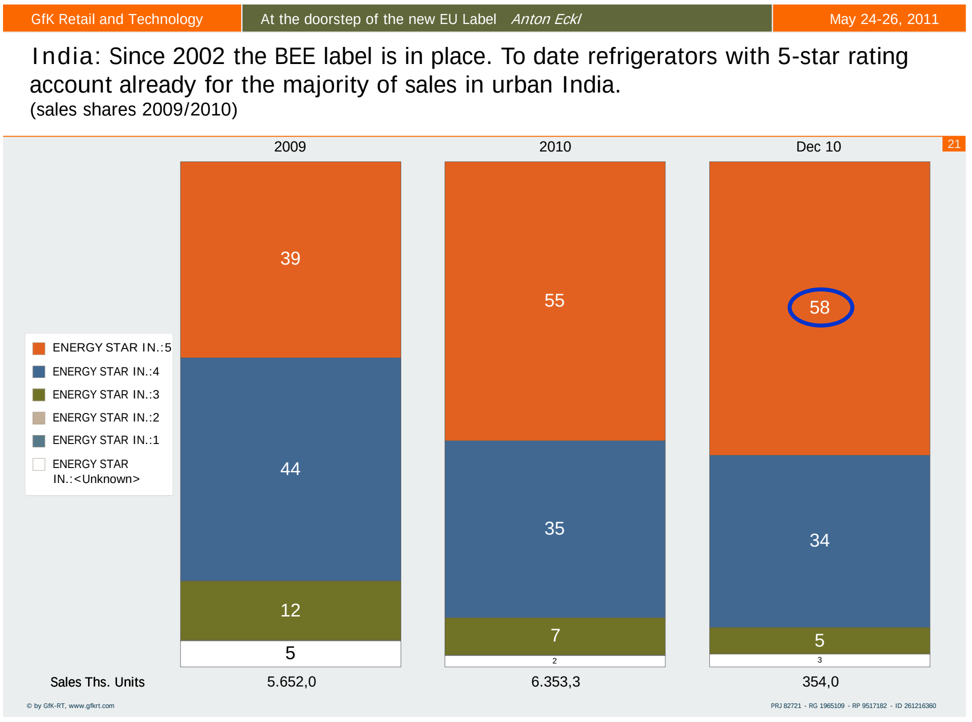


Figure 15: Sales shares for Cooling/refrigerators by India Energy Star Rating 2009/2010

Figure source: GfK Retail and Technology Retail Audits

China

The Chinese Energy Label was introduced in 2005 for refrigerators, washing machines followed in 2007 as well as air conditioners. At first glance it has some similarities to the EU-label, but is based in different standards and working with a 1 (good) -5 (bad) scale.

Class 1 is already dominant in Cooling/refrigerators with 71% and the growing segment in washing machines (see fig. 15).

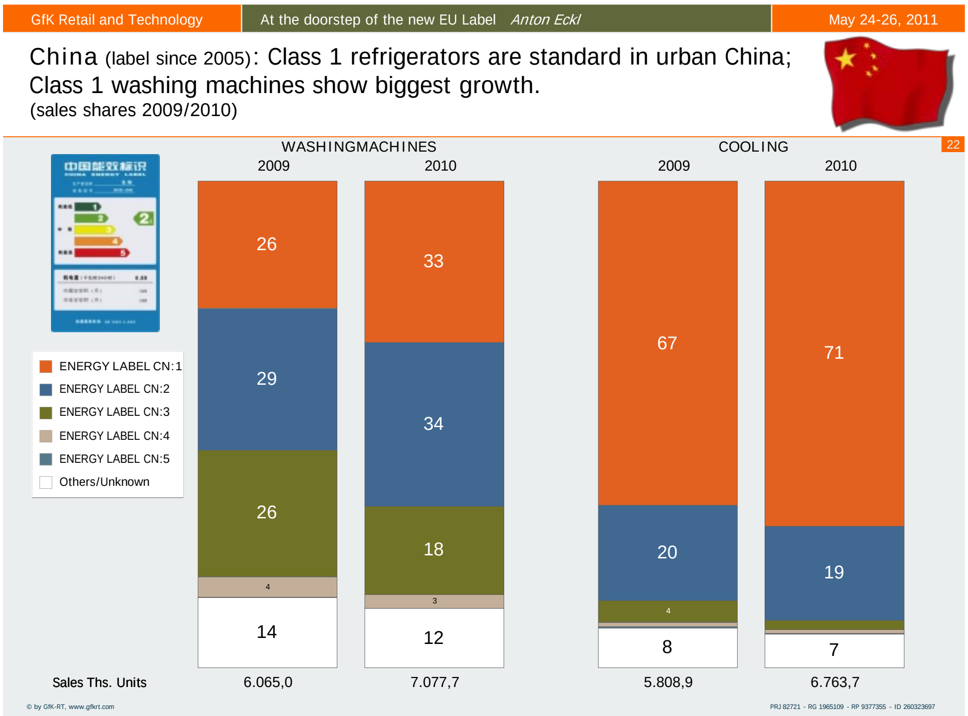


Figure 16: Sales shares for Washing Machines and Cooling/refrigerators by China Energy Label 2009/2010

Figure source: GfK Retail and Technology Retail Audits

In the European style Drum Type machines sub-segment the share of Class 1 products is already 97%, whereas the share in the most common Asian style Single Tubs is only at 14% and still not existing on the cheap and very basic Twin Tubs (see fig. 16).

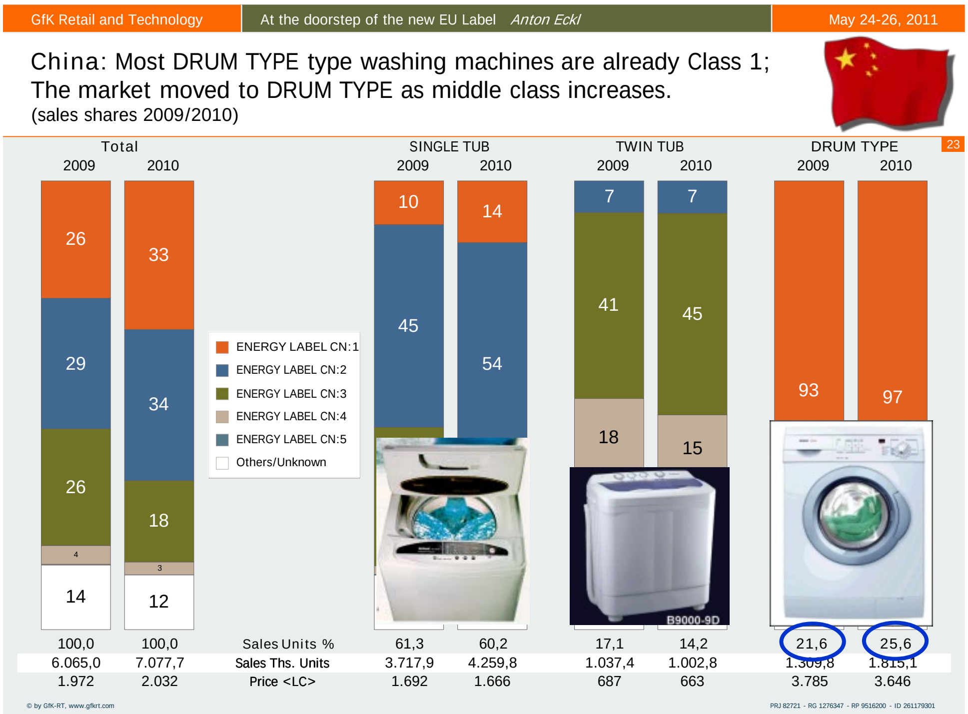


Figure 17: Sales shares for Washing Machine Types by China Energy Label 2009/2010

Figure source: GfK Retail and Technology Retail Audits

Summary

A change in European energy policy can be expected in the wake of the recent accident in the Fukushima atomic power plant in Japan. The safest and cheapest kilowatt hour is every kilowatt hour not spent. Therefore energy efficiency will be more in the focus for the years to come than ever before.

Already in the past, energy efficiency for White Goods was of a very high relevance in the r&d process of manufacturers and the decision making process of consumers. This is understandable as White Goods account for example in Germany for 50% of the average household's electricity consumption.

The EU label did a great job for the market transformation to more energy-efficient appliances, but now it was high time for a revision.

Evidence given by first GfK sales data on the new label suggests that highly efficient appliances are still pretty expensive. Are subsidies a possible solution to boost the sales in the early phase?

Also outside Europe there is need for a revision of labels in several countries as this paper explained.

Roadmap for the Next Generation of CLASP's Global S&L Database

Christopher Wold, Program Associate
James McDonald, Technology Steward
Frank Klinckenberg, Technical Director

Collaborative Labeling and Appliance Standards Program (CLASP)

Abstract:

The Collaborative Labeling and Appliance Standards Program (CLASP)'s primary objective is to identify and respond to the assistance needs of standards & labeling (S&L) practitioners in targeted countries and regions, while making the highest quality technical information on S&L best practices available globally. To this end, CLASP works to deepen S&L knowledge through the Global S&L Database – a centralized database of S&L programs that encompasses over 80 economies and spans over 200 product categories. This paper conducts a thorough assessment of the database and identifies improvements that will increase the richness and accuracy of information provided. It goes on to further explain these improvements, which include: a comprehensive redesign; the development of new features such as an S&L timeline; and the initiation of a new strategy for managing updates. The paper concludes by summarizing CLASP's timeline for the implementation of these improvements.

History and Background:

CLASP is an international non-governmental organization (NGO) working to reduce global energy consumption and carbon dioxide (CO_2) emissions through energy efficiency standards and labeling (S&L) programs. Over the past decade, CLASP has assisted over 50 countries on six continents to develop and improve their S&L programs for lighting, appliances, electronics, and commercial equipment. As part of CLASP's mission to deepen S&L knowledge globally, CLASP has created a comprehensive database of international S&L programs. CLASP's Global S&L Database tracks standards, labels, and test procedures for over 200 product categories[1] in over 80 economies.[2] Database users include government officials, policy makers, manufacturers, and S&L practitioners. The Database is utilized as a research tool for:

- Standard, label, and test procedure harmonization;
- Standard, label, and test procedure development;
- Scoping of S&L programs in an economy or region; and
- Analysis of S&L program gaps as compared to other economies.

Using funding from the United States Agency for International Development (USAID), CLASP engaged the International Institute for Energy Conservation (IIEC) to compile the initial Global S&L Database in

[1] Product categories are defined by a combination of attributes including end use, function, energy source, etc. For example, residential gas boilers and residential electric boilers are two distinct product categories, as are residential gas boilers and commercial gas boilers.
[2] For the purposes of the Database, "economies" refer to national entities such as Brazil, the United States, and Canada, as well as economic entities such as Hong Kong and the European Union.

2000. Its initial form was a simple spreadsheet listing economies with S&L programs and the products covered by these programs. In 2004, the Database was comprehensively redesigned and expanded to include the Economy Pages, S&L Program Pages, and Product Pages. The expansion dramatically enhanced the information provided with summaries of S&L programs.

APEC-ESIS:

CLASP's relationship with the Asia-Pacific Economic Cooperation (APEC) began in 2004 when CLASP became an observer of the Expert Group on Energy Efficiency and Conservation (EGEE&C). This group is composed of representatives from APEC member economies who collaborate to reduce energy consumption in the APEC region through energy efficiency programs. In 2008, the EGEE&C engaged CLASP in the development of an S&L database for APEC economies called the Energy Standards and Labeling Information System (ESIS). With prior experience managing a global database, CLASP volunteered to act as the Secretariat of ESIS. A decision was made to co-locate both databases on the same server, which effectively synchronized both datasets so that each pulls data from the same data source. Linking the databases enhances content on both by combining data provided by the APEC economies with data generated through CLASP research.

Database Functionality & Design:

The Global S&L Database is housed on CLASP's website (www.clasponline.org) and is freely accessible without additional tools or login requirements. It is one of many tools that CLASP provides as part of its mission to make the highest quality technical information on S&L best practices available to the global community. The Database's interface focuses on presenting results in three primary data areas: the Economy Pages, the S&L Program Pages, and the Product Pages. The Database can be searched via two dropdown menus located on CLASP's homepage and other pages on the CLASP website.

Dropdown Menus:

There are two primary criteria by which a query to the Global S&L Database can be initiated, accessible via dropdown menus. The Economy Dropdown allows a user to access information about S&L programs within a particular economy, while the Product Dropdown allows a user to access information on S&L programs worldwide for a particular product category.

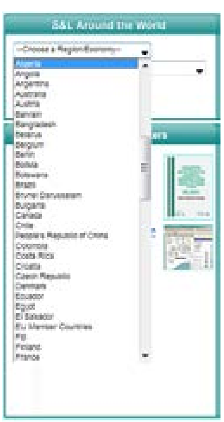


Figure 1: Economy Dropdown

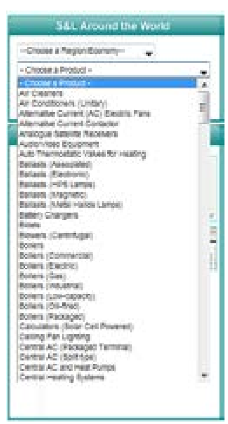


Figure 2: Product Dropdown

Economy Pages:

When a user searches by economy, the results are displayed in a so-called "Economy Page." The Economy Pages are profiles that contain information on S&L programs for over 80 economies. Each economy in the Database has a corresponding Economy Page. The Economy Page is a central access point for information on S&L programs within a particular economy. Every Economy Page contains the following information:

- A general overview and description of the economy's S&L programs;
- A comprehensive list of all product categories covered by S&L programs;
- Contact information for key economy experts; and
- Related web links.

An example of an Economy Page is represented in Figure 3 below.

S&L Around the World

The United States

The United States makes extensive use of information labels, quality marks and standards to improve the energy efficiency of appliances and equipment. As of June 2001, a large number of products are required to carry energy information labels and to meet minimum energy efficiency standards. In addition, endorsement labels (Energy... More details click here...

Summary of Labeling Programs and Technical Standards

- Mandatory Label (25)
- Voluntary Label (62)
- Minimum Energy Performance Standard - Mandatory (52)
- Minimum Energy Performance Standard - Voluntary (1)
- Energy Performance Testing Standard (114)
- Related Website Links (18)
- Economy Contacts (2)
- Related S&L Library Resources (100)

Summary Table by Equipment Type

Yv = Yes, voluntary; Ym = Yes, mandatory; U = under consideration

Equipment Type	Minimum Standard	Labeling	National Test Standard	Reference Test Standard
Air Cleaners		Yv(1)	ANSI/AHAM AC-1 ENERGY STAR Requirements for Room Air Cleaners	
Audio/Video Equipment		Yv(1)	ENERGY STAR Requirements for Audio/Video V 2.0	IEC 62301
Ballasts (Electronic)	Ym(1)	Ym(1)	10 CFR Part 430 Appendix Q to Subpart B	ANSI C 82.2
Ballasts (Metal Halide Lamps)	Ym(1)		10 CFR Part 431.324	ANSI C82.6-2005
Battery Chargers	U(1)	Yv(1)	10 CFR Part 430 Appendix Y to Subpart B ENERGY STAR Requirements for Battery Charging Systems	IEC 61951-1 IEC 61951-2 IEC 61960 IEC 62133 IEC 62301
Boilers (Commercial)	Ym(1)		10 CFR Part 431.86	
			10 CFR Part 430 Appendix N	

Figure 3: Economy Page for United States S&L Programs

S&L Program Pages:

From within each Economy Page, it is possible to pare down to view information on that country's specific S&L programs. This information is displayed to the user in the "S&L Program Pages." These pages are specific to an economy and contain detailed information about S&L programs within the economy for each product category. An image of an S&L Program Page is depicted in Figure 4 below.

S&L Around the World

S&L Programs for CFLs in The United States

Standard Program(s)

- MEPS for Medium Base Compact Fluorescent Lamps (CFLs)

Labeling Program(s)

- EnergyGuide - Medium Base Compact Fluorescent Lamps (CFLs)
- ENERGY STAR - Compact Fluorescent Lamps

EnergyGuide - Medium Base Compact Fluorescent Lamps (CFLs)

Program Type: Mandatory Label

Product : CFLs

Economy : The United States

Test Standard : 10 CFR Part 430 Appendix W to Subpart B ENERGY STAR Criteria for CFLs V 4.0

Reference Test Standard : ANSI C78.376 , ANSI C78.5 , ANSI C78.901 , ANSI/IEEE C62.41 , CIE 18.2 , ENERGY STAR Criteria for CFLs V 4.0 , IESNA LM-16 , IESNA LM-28 , IESNA LM-40 , IESNA LM-41 , IESNA LM-54 , IESNA LM-65 , IESNA LM-66 , IESNA LM-9 , UL 1598 , UL 1993 ,

Description :

Range of Products Covered:

An integrally ballasted fluorescent lamp with a medium screw base, a rated input voltage range of 115 to 130 volts and which is designed as a direct replacement for a general service incandescent lamp; however, the term does not include—

(1) Any lamp that is—
(i) Specifically designed to be used for special purpose applications; and
(ii) Unlikely to be used in general purpose applications, such as the applications described in the definition of "General Service Incandescent Lamp" in paragraph (n)(3)(ii) of this section; or

(2) Any lamp not described in the definition of "General Service Incandescent Lamp" in this section and that is excluded by the Department of Energy, by rule, because the lamp is—
(i) Designed for special applications; and
(ii) Unlikely to be used in general purpose applications.

Year Published : 1989

Year Effective : 2007

Figure 4: United States S&L Program Page for CFLs

Product Pages:

When a user chooses to search via product, the information they receive is presented in a product profile page. These so-called "Product Pages" contain information about worldwide S&L programs for over 200 product categories. Each product category within the Database has a Product Page which contains information about applicable worldwide S&L programs for the given product category, as demonstrated in Figure 5 below.

S&L Around the World

Clothes Washers

Summary of Labeling Programs and Technical Standards

- Mandatory Label for Clothes Washers Worldwide (21)
- Voluntary Label for Clothes Washers Worldwide (22)
- Minimum Energy Performance Standard - Mandatory for Clothes Washers Worldwide (14)
- Minimum Energy Performance Standard - Voluntary for Clothes Washers Worldwide (5)
- Energy Performance Testing Standard for Clothes Washers (33)
- List of Economies Implementing S&L Programs Clothes Washers (37)

Additional Resources from CLASP

- Related S&L Library Resources (9)

Summary Table by Economy

Yv = Yes, voluntary; Ym = Yes, mandatory; U = under consideration

Economy	Minimum Standard	Labeling	National Test Standard	Reference Test Standard
Algeria	U(1)			
Argentina		Ym(1)	IRAM 2141-3	
Australia		Ym(1)	AS/NZS 2040.1:2005/Amdt1:2007	
Austria		Yv(1)		
Brazil	Yv(1)	Ym(1) Yv(1)	RESP/005 Projeto de Norma ABNT 03:059.05-025 de 07/1999	
Canada	Ym(1)	Ym(1) Yv(1)	CAN/CSA-C 360-03	
Chile		U(1)	NCh 2582: 2001	
Chinese Taipei		Yv(2)	CNS 2926	JIS C 9606
Colombia	Yv(1)	Yv(1)		
Czech Republic		Yv(1)		
Egypt	Ym(1)	Ym(1)		
EU Member Countries	Yv(1) U(1)	Ym(1) Yv(1)	EN 60456	
Germany		Yv(1)		

Figure 5: Product Page for Clothes Washers

Database Limitations:

While stable, the current version of the Global S&L Database is currently hosted in an environment that presents a number of limitations. From a management standpoint, the dataset presently requires advanced technical intercession to maintain. Furthermore, the present configuration of the Database limits the ability to capture and query properties of the data that would provide significant assistance to researchers. Specifically, the Database lacks a method for denoting the status of standards and labels. Presently, it is not possible to differentiate standards and labels that are currently in effect from standards and labels that are either under consideration[3] or under development[4]. Additionally, there is no clear way to distinguish when an existing standard or label undergoes a revision.[5]

The ability to divide the Database between different status types (existing, under consideration, under development, and under revision) is critical to identifying new opportunities for international and regional collaboration on the development and revision of standards and labels. To provide this augmented functionality, CLASP is undertaking an enhancement of the Global S&L Database, which will involve moving the tool to a new server, constructing a user-friendly management interface, and revising the database schema to support new ways of categorizing and querying information.

Database Maintenance:

The Global S&L Database has grown from tracking S&L programs for 80 product categories in 45 economies to over 200 product categories in over 80 economies. The substantial growth of the dataset has made it increasingly difficult to maintain. Data routinely becomes outdated as economies add new standards and labels, as well as revise existing ones. A constant database update process is required to remedy this issue. The process of updating the Database requires active research, including online searches, document translation, identifying and contacting regional experts, obtaining information from government agencies, and verifying or clarifying data. Additionally, this type of research requires knowledge of S&L programs and product technology.

Organizing programs into product categories requires technical and policy expertise. Categorizing products can be confusing, as no universally-accepted taxonomy exists, and economies categorize products differently. To further complicate matters, some products are functionally the same yet technologically different. For example, central air conditioners in the United States are technologically different from central air conditioners in Japan. In Japan, central air conditioners use a variable speed motor while in the US central air conditioners use a single or dual speed motor. Therefore, it is necessary that personnel tasked with content maintenance have a basic understanding of S&L programs and product technology before updating the Database.

In the past, CLASP has implemented a number of methods to keep the Database up to date, including the hiring of S&L experts. CLASP has hired experts from Lawrence Berkeley National Laboratory (LBNL) and IIEC to conduct comprehensive updates of the Database contents. These updates were paid for with funding from the United States Department of Energy (DOE) and the Renewable Energy & Energy Efficiency Partnership (REEEP). In between these comprehensive updates, CLASP used a number of other methods to maintain the Database. The following table reviews all of these methods and provides an assessment of their strengths and weaknesses:

---

[3] Under Consideration – occurs when a rulemaking body is considering the development of a standard and/or label for a product.
[4] Under Development – occurs when a rulemaking body is in the process of developing a standard and/or label for a product.
[5] Under Revision – occurs when a rulemaking body has decided to or is in the process of updating the specifications for an existing standard and/or label.

Table 1: Assessment of Updating Methods

Update Method:	Description of Method:	Strengths and Weaknesses:
Volunteered Updates	CLASP periodically receives comments from Database users who have identified errors in the Database. Errors include data that is incorrect, missing, or out of date. CLASP personnel must either research a correction or verify the accuracy of a correction if one was provided.	User feedback is a valuable tool for identifying errors but cannot be solely relied upon to maintain the Database. Most importantly, not all users will realize the errors and will use the incorrect data in their research.
Key Economy Contact	One of the ways in which the APEC-ESIS database is updated is through the identification of key economy contacts. Key economy contacts are government officials who have volunteered to review the accuracy of data presented in the Database and provide regular updates. In the past, IIEC would contact key economy contacts twice a year on behalf of CLASP requesting a review and update of data.	Data obtained from key economy contacts is accurate and comprehensive. Although, problems arise when eliciting a response from economy contacts. Regular government staffing changes frequently cause the list of economy contacts to become out of date. Additionally, updates are not always a high priority for busy government staff and requests often go unanswered. Economy contacts are best utilized as one of many tools for researching updates.
Contracted Expert	Periodically, CLASP has contracted outside experts to conduct a comprehensive update of the Database.	Contractor updates are both comprehensive and accurate, but lack a mechanism for maintaining data after the update has been completed. Additionally, global S&L knowledge developed during the update is not retained in-house for the benefit of future Database improvements.
In-House Researcher	Assigned CLASP team members update and maintain the Global S&L Database.	Updates are comprehensive and accurate. Global S&L knowledge developed during updates is retained in-house, it requires staff time to update and maintain the Database. This method, however, has the added benefit of acting as a research training tool for in-house staff that can be applied to other projects and programs at CLASP.

New Method for Database Maintenance:

After reviewing the previous methods for maintaining the Database, CLASP concluded that a new strategy for maintenance of the data was needed. Since 2008, CLASP has undergone substantial organizational growth, expanding from two to 23 team members and opening new offices in Brussels, New Delhi, and Beijing. A new strategy was developed to capitalize on the size and regional distribution of the CLASP team.

Starting in mid 2011, the Global S&L Database will be updated and maintained in-house with responsibility distributed among all CLASP programmatic team members,[6] including team members in CLASP's regional offices. Each team member will be responsible for four to six economies with the larger economy programs (China, Australia, the USA, et.al.) equally distributed. Team members will be assigned geographical regions, with preference given to team members already located in a particular region. The new strategy accomplishes the following goals:

- Develops in-house regional expertise;
- Utilizes the already-existing regional distribution of team members;
- Benefits country programs in China, India, and the US by developing firsthand knowledge about S&L programs in neighboring countries; and
- Provides a cost effective method for ensuring the Database receives regular updates.

Database Redesign:

In 2008, CLASP became the S&L Best Practice Network (BPN) for the Climate Works Foundation (CWF). With their support, CLASP has received funding to improve and expand CLASP's website, including the Global S&L Database. When completed, the Database will have a number of improvements and new features, including:

- Updated and expanded product and S&L program data;
- Development of an S&L timeline;
- Inclusion of test procedure summaries;
- Enhanced data sharing;
- Creation of a maintenance interface that permits data updates without in-depth knowledge of database management; and
- Compliance with internationally recognized standards for access by visitors with disabilities.

Redesign Approach and Methodology:

Enhancing and expanding a database-driven tool such as the Global S&L Database requires several phases of analysis and planning. A strategy phase was conducted first, whereby an assessment was made of the status quo, enhancements were identified, and comprehensive documentation of intended changes was drafted. This documentation was then used to solicit external assistance in database development and user interface design.

The strategy phase was followed by a discovery phase. This is where the project stands at the time of this writing. During this phase, the existing Database is assessed from three layers: the underlying code; the content itself; and the presentation of the content. Potential areas of enhancement or modification are

[6] Programmatic Team Members - team members that work on CLASP's technical and policy research activities.

identified and combined with the initial scope defined in the strategy phase. In this phase, a determination is made of what structures inside the Database will remain intact and which ones will change. This combined documentation forms the basis of technical specifications for the construction of the new tool and guidelines for the migration of content from the old to the new Database.

The technical specifications are then used by the development team to construct a database and used by content experts to conduct content update and migration preparations.

Once the new Database has been developed and the content has been migrated, it will be tested for proper operation during a quality assurance process. After successful testing, the tools available in the new Global S&L Database will be released as a portion of the refashioned CLASP website. The process which began in mid-2010 should be completed in July of 2011. Figure 6 below depicts CLASP's timeline for redesigning the Database.

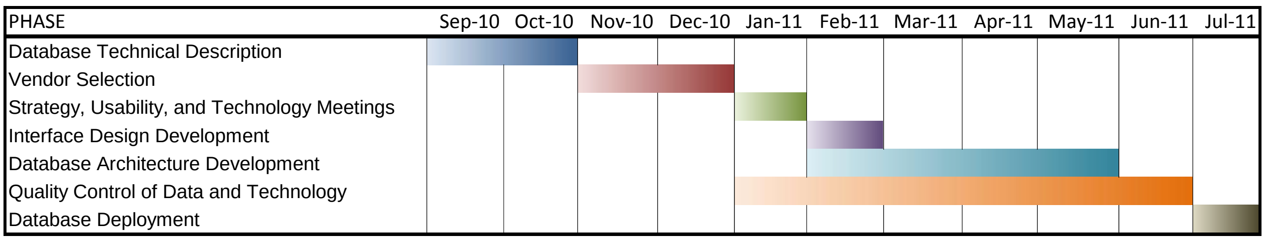


Figure 6: Database Redesign Timeline

Migration and Content Update:

Rather than perform a direct transfer of the content, CLASP will conduct a comprehensive review and update of all data before migrating it to the new Database. This process will be conducted in-house by the same CLASP team members who will be charged with maintaining the Database after its relaunch. Additionally, CLASP will review the nomenclature by which product categories are determined in order to improve the Product Pages.

New Functionality – S&L Timeline:

CLASP will develop a new feature that will track the development and revision of standards and labels using regulatory schedules published in the public domain. The timeline will have two displays: Economy Timeline and Product Category Timeline. The Economy Timeline will display all product categories undergoing the development and/or revision of standards and labels within a particular economy. The Product Category Timeline will display all worldwide rulemaking activity for the development and revision of standards and labels for a particular product category. These new features will support international and regional collaboration on the development and revision of standards and labeling programs. Examples of both timelines are represented in Figure 7 and 8 below.

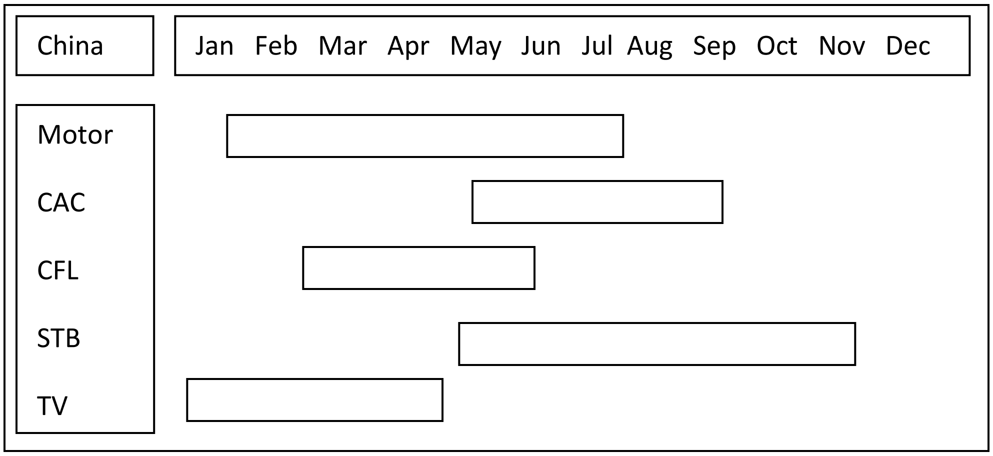


Figure 7: Example of an Economy Timeline

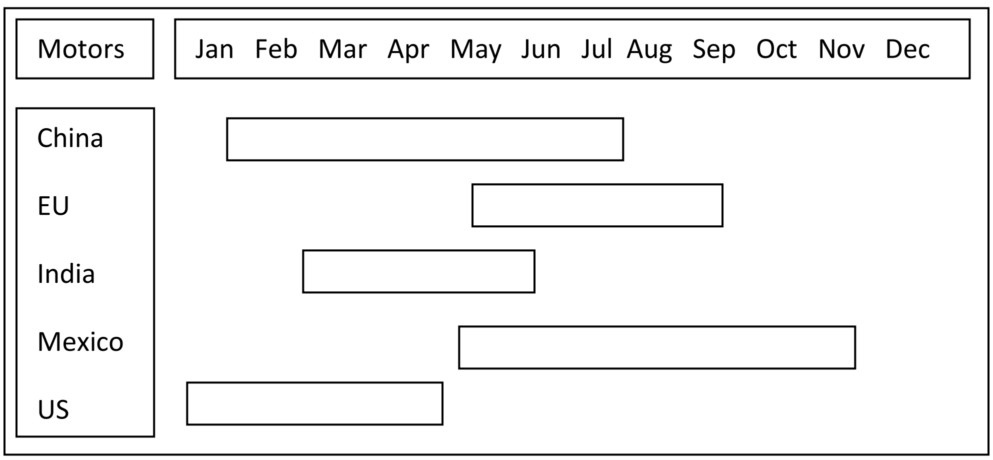


Figure 8: Example of a Product Category Timeline

New Functionality – Test Procedure Summaries:

CLASP will expand the technical information provided on the Database by adding summaries of test procedures. Test procedures are the method by which product energy consumption is measured. In many cases, an economy will adopt an international test procedure and then adapt it to suit their needs. CLASP will add a summary of the international test procedures for key products, including an explanation of how these test procedures have been adapted in key economies. This information does not currently exist on any other database and will be highly useful for test procedure harmonization.

New Functionality – Data Portability:

While the current Database allows for the sharing of data with APEC-ESIS through the co-location of both databases on the same server, the new Database will be specifically equipped with a portability function that will allow the data to be shared with affiliate organizations on other servers. This new feature will provide greater collaboration and allow for greater access to S&L information.

Additional Features:
The look and feel of the Database will also be improved based on input from user experience and design experts. The Database interface will also be brought into compliance with internationally recognized

standards for accessibility, permitting the visually impaired to easily navigate and utilize the Database. Additionally, a mobile phone application is planned so that the Database can be easily accessed using these types of devices.

Conclusion:

This paper has chronicled CLASP's assessment of the current database, identification of enhancements, and approach to the construction of the new Database. Once deployed, the Database will provide increased access to information, dynamic tools, and a stable platform for future growth. CLASP's aim is for the Global S&L Database to further global understanding of S&L programs and provide new opportunities for international collaboration.

The evolution and interaction TV MEPS and labeling around the world

Mia Forbes Pirie and Keith Jones

Lawrence Berkeley National Laboratory and Digital CEnergy Australia Pty Ltd

Abstract

Televisions and other consumer electronics products differ from more traditional home appliances like refrigerators and dishwashers. In terms of energy consumption in the home, however, televisions now rival appliances such as refrigerators. They are characterized by relatively high innovation, faster time-to-market, and rapid transition from one technology to another. This makes the regulation of these products more challenging. In some cases the pace of technology change can exceed the pace of developing energy efficiency standards for televisions and other complex consumer electronics products.

This paper compares and contrast emerging and existing international energy efficiency programs for televisions (focusing on Australia, California, Canada, China, EU, Korea, the USA, and Japan). It considers the evolution of technology, how this has affected what is possible in terms of TV MEPS and how international standards can build and have built on each other.

Topics covered include:

- convergence
- emerging technologies – 3D and IPTV
- Energy Saving Modes and relating energy use to viewing environments including ABC and room illuminance levels
- Challenges for measurement such as luminance measurements across technologies.
- Challenges for harmonization of programs and standards
- Challenges of rapidly changing technologies and costs
- Challenges of energy use efficiency measures.
- A review of recent results from existing programs (in particular Australia and Energy Star)
- The advantages of international collaboration

Introduction

Televisions and other consumer electronics products differ from more traditional home appliances like refrigerators and dishwashers. In terms of energy consumption in the home, however, televisions now rival appliances such as refrigerators. They are characterized by relatively high innovation, faster time-to-market, and rapid transition from one technology to another. This makes the regulation of these products more challenging. In some cases the pace of technology change can exceed the pace of developing energy efficiency standards for televisions and other complex consumer electronics products.

This paper compares and contrast emerging and existing international energy efficiency programs for televisions (focusing on Australia, California, Canada, China, EU, Korea, the USA, and Japan). It considers the evolution of technology, how this has affected what is possible in terms of TV MEPS and how international standards can build and have built on each other.

Comparative review of television S&L programmes world wide

The process for setting programmes for each of the regions being considered is outlines below. A table is presented (Table 1) that provides an outline of each regions TV programme.

California and other US States

In the US, Federal MEPS (known as energy conservation standards) pre-empt State MEPS. Thus far (at the time of writing), there have never been federal MEPS for TVs in the US. Accordingly, the individual States may pass their own MEPS into law. California has done this and other States (Massachusetts, New York and Washington) are considering following suit.

Once US Federal MEPS are enacted, any State MEPS will no longer be relevant. The legislative processes and the analysis typically underlying the setting of MEPS differs significantly between the Federal level and the State level. This section provides a high-level overview of the process and MEPS in place in California and other States. A description of the US standards and analytical process is also set out below.

Overview of Programme

California

The California Energy Commission (CEC) adopted new television standards on November 18th, 2009. The standards establish the first-ever active mode power usage limits in the US and, so far, the highest mandatory standard in the world. The new active mode standards are designed to be implemented in two phases. Tier 1 became effective on January 1, 2011; Tier 2, similar to ENERGY STAR 4.1, will be effective on January 1, 2013, 30 months after Energy Star 4.0 became effective.

Tier 2 is close to the level of Energy Star 4.1. When this standard was tabled by the CEC, many were concerned that it would be difficult for industry to meet. Since, most manufacturers either claim that they already meet the standard or will meet it in early 2011.

Others States

Three other States are considering MEPS for TVs mirroring the California Standards:

1. Energy Efficiency Standards Bill for TVs is pending in Massachusetts, mirroring the California standard.
2. New York State Assembly member Brian Kavanagh has introduced legislation on Jan. 2010 to mirror television energy efficiency standards that were adopted by California.
3. Similar legislation to adopt California's TV standards has also been introduced in Washington (HB2416) in Feb. 2010.

Summary of Programme Setting Process

[To be completed]

Summary of European Union Programme Setting Process

The Framework Directive for the Eco-design of Energy Using Products (EuP) was adopted in July 2005 and implemented in the EU Member States (MS) in August 2007. In October 2009 the Ecodesign Directive was amended to include Energy Related Products (ErP) as well as Energy Using Products[1]. The Ecodesign Directive allows consideration of both products that use energy directly (e.g. computers) and products which have indirect impacts on energy use (e.g. windows). The Ecodesign Directive provides the ability to set European Union (EU) wide measures to improve the environmental performance of energy related products (ERPs).

The Ecodesign Directive process consists of:

---

[1] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products, available from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0125:EN:NOT

1. The European Commission (EC) develops a working plan which sets out a 3 year plan of priority Products;

2. The priority products are then investigated within a preparatory study to assess what Ecodesign measures should be developed and their form.

3. The preparatory study the products are assessed to identify potential energy savings potential and costs for industry resulting from these changes.

4. The EC next assesses the outcomes of the study and develops a draft Commission Regulation if deemed suitable.

5. This draft regulation is submitted to the "Consultation Forum" which is made up of representatives from the EU and EEA member states as well as a maximum of 30 external stakeholders from industry, non-governmental organisations (NGOs) and consumer organisations.

Following the Consultation Forum the draft regulatory measure is submitted for vote by the Regulatory Committee which consists of representatives from EU member states. If approved the draft Commission regulation undergoes evaluation by the European Parliament before being implemented into law.

Summary of Australian Programme Setting Process.

The normal process followed by Australia to implement a MEPS or labelling programme starts with the development of a scoping and discussion paper which is then released for stakeholder comment. The comment period varies but 6-8 weeks is considered adequate. During the comment period a stakeholder meeting is held to discuss the paper and any possible programme options. At the conclusion of the comment period submissions are analysed and a recommendation is made about how the programme should move forward. These recommendations are then considered by the E3 committee for a decision to move forward.

If the decision is to pursue a regulated MEPs and/or labelling programme a Consultation Regulatory Impact Statement is prepared (RIS), This RIS must be approved by the Office of Best Practice Regulation (OBPR) before it can be released for public comment. When the RIS is released for comment a second stakeholder meeting is held to discuss the consultation (RIS). At the conclusion of the consultation period the submissions are considered and the consultation RIS is reworked into a decision RIS. This RIS must also be approved by OBPR before it can be considered by the E3 committee and the Ministerial Council on Energy (MCE) for approval.

Concurrently with the development of the decision RIS Standards Australia is commissioned to create the technical and programme requirements standards associated with the programme. This standards development follows the same procedure as any normal standards development using a committee of stakeholders to approve the publishing of the standards.

Once approved by the MCE the individual states enact legislation or regulation as appropriate which call up the Standards Australia documents as the technical and programme requirements.

Summary of China Programme Setting Process.

China first adopted minimum energy performance standards (MEPS) in 1989. Today, there are standards for a wide range of domestic, commercial and selected industrial equipment. In 2005, China started a mandatory energy information label (also referred to as the "Energy Label"). Today, the Energy Label is applied to four products including:

- air conditioners;
- household refrigerators;
- clothes washers; and
- unitary air conditioners.
- Televisions

China National Institute of Standards (CNIS) is empowered by law to create and enforce standards in the areas mentioned above. Its standards equally apply to Chinese produced equipment and imported equipment. CNIS aims to eliminate poor energy performing product from the market. Non compliance results in fines and forced removal of product from the market place. Although CNIS can implement standards as directed by policy without consultation it is normal for CNIS to conduct stakeholder consultation. This is evidenced from the recent implementation of their TV labelling and MEPS programme which came into force on the 1st December 2010. The last stake holder meeting for this programme was conducted on the 25th November 2010

Summary of Japan Programme Setting Process.

Top Runner is a regulatory scheme designed to stimulate the continuous improvement of the in-use energy efficiency of products within selected segments of markets such as household and office appliances. Top Runner was first implemented in Japan in 1998 as part of the Energy Conservation Law. The program set mandatory energy efficiency standards, based on the most efficient products on the market, for a variety of appliances, equipment, and automobiles. The programme initially covered 9 products in 1998 and has been increased to 21 products in 2009.

The scope of the Top Runner Program is based on three criteria:

1. products involving large domestic shipments;
2. products that consume a substantial amount of energy in the "in use" phase;
3. products with considerable propensity to improve energy efficiency.

For the Top Runner programme, the most energy efficient product on the market during the standard-setting process sets the Top Runner Standards. The Top Runner programme also considers technological potential for efficiency improvement in the future

In Japan, energy efficiency standards are discussed and determined by the Ministry of Economy, Trade and Industry (METI) and its advisory committees comprising representatives from academia, industry, consumer groups, local governments, and mass media. The Advisory Committee for Natural Resources and Energy is in charge of overall energy policy including energy efficiency policy. It usually takes about a year or two to set the standards for one product (ECCJ, 2008). The METI also considers revision of standards when the target year is reached.

In order to comply with the Top Runner Standards, producers must ensure that the weighted average energy efficiency of the products they sold in the target year achieves the requisite standards. Therefore, not all of a manufacturer's products have to meet the target, but on average, they must achieve the standards. This flexibility enables producers to provide a wide range of models to meet the market demand while guiding the overall market to higher energy efficiency.

In the target year, the METI requires the producers to submit a report on their sales and the energy efficiency of their products, and then evaluates their compliance. In case of non-compliance, the Top Runner Program takes a "name and shame" approach. The Ministry first makes a recommendation to the non-compliant producer to improve their energy efficiency performance, goes public with the recommendation when the producer does not comply, and finally orders the producer to meet the recommendations (ECCJ, 2008).

Summary of Energy Star Programme Setting Process.

Product Development (PD) teams at EPA follow a pre-defined evaluation process to assess whether the development or refresh of an ENERGY STAR specification is required. The PD teams secure expertise and resources of other stakeholders (such as including manufacturers, utilities, environmental groups, and other government agencies). These teams are also required to follow the ENERGY STAR Specification Development Guiding Principles when determining products to be covered by the label, and during the development or revision of the product specific specifications:

The actual specification development cycle can be separated into the following stages:

1. Stakeholder notification about the potential specification development or revision
2. Energy and environmental analysis of the products in question
3. Research into market, industry and design data
4. Development of a suitable test methodology

5. Release of a draft specification
6. Stakeholder meeting arranged to discuss draft specification
7. Release of amended drafts following stakeholder discussions
8. Drafts and stakeholder comments posted to website
9. European Commission Energy Star Board (ECESB) meet to approve draft final specification
10. Finalisation of the specification (at least 9 months before requirements are due to be implemented)
11. Development of final decision memorandum
12. Implementation of the specification - conduct an official launch of the specification with industry and stakeholders, and labelling of manufacturers' products commences
13. Continually monitor market penetration
14. Open specifications for revision when necessary

Summary of Korea Programme Setting Process.

The Ministry of Commerce, Industry and Energy (MOCIE), through *Korea Energy Management Corporation* (KEMCO), operates three energy efficiency programs to facilitate low energy using products. These programs are

1. Energy Efficiency Standards & Labelling Program,
2. Certification of High Efficiency Energy-using Appliance Program
3. Energy-Saving Office Equipment & Home Electronics Program.

The objective of these programs is to encourage manufacturers to improve their products' efficiency by giving incentives and to induce consumers to purchase the higher energy efficient products available.

The Energy Efficiency Label and Standard Program targets products with high energy consumption, requiring mandatory indication of the energy efficiency rating. The rating varies from 1 to 5. Any products falling below the 5 rating are prohibited from production and sale (effectively applying a MEPS).

The High-efficiency Appliance Certification Program promotes the high efficiency of products by certifying products that perform above certain standards. Certified products may bear the High-efficiency Equipment Label and certificates are also issued.

The e-Standby Program attempts to promote energy saving products by reducing standby power based on manufacturers' voluntary participation. An "Energy Boy" label addresses those consumer electronic and office equipment appliances that have high potential for reduction of standby power. The label is placed on products which satisfy the standby power reduction standards set by the government. The categories of products included in this program include household appliances and office equipment.

KEMCO is authorized to monitor whether the manufacturers or importers of appliances with energy efficiency rating label observe this program or not. In particular KEMCO does market-place inspection and product inspection.

In accordance with the Article 18 and 19 of *The Rational Energy Utilization Act*, the manufacturers or importers of appliances labelled with the energy efficiency rating should indicate the certified grade, the energy efficiency and the means in which the product can be used most efficiently in the advertisements or the product manuals. If they do not illustrate these, a penalty of as much as 5 million won (approximately US $4,170) will be imposed on them.

Summary of Canada's Programme Setting Process.

[To be completed]

Overview of U.S. Appliance Standards Setting and Analytical Process[2]

The U.S. Department of Energy (DOE or the Department) Appliances and Commercial Equipment Standards Program, within the Office of Energy Efficiency and Renewable Energy (EERE) Building Technologies Program (BT), develops and promulgates test procedures and energy conservation standards for consumer appliances and commercial equipment. The process for developing standards involves analysis, public notice, and consultation with interested parties. Such parties, known as stakeholders, include manufacturers, consumers, energy conservation and environmental advocates, State and Federal agencies, and any other groups or individuals with an interest in these standards and test procedures.

Part B[3] of Title III of the Energy Policy and Conservation Act (EPCA) of 1975, as amended, created the Energy Conservation Program for Consumer Products Other Than Automobiles. The 1978 National Energy Conservation Policy Act (NECPA), Pub. L. 95-619, which amended EPCA, required the DOE to establish mandatory energy conservation standards for each of the 13 listed "covered products". In 1987, the National Appliance Energy Conservation Act (NAECA), Pub. L. 100-12, amended EPCA by refining the list of covered products and establishing Federal energy conservation standards for 11 of the 12 products on the revised list. Television sets were listed as a covered product under both the NECPA and NAECA amendments.

Televisions have a unique status under EPCA: although they are listed as a covered product, the statute does not require a standard. Moreover, with regard to rulemakings, EPCA provides the Secretary of Energy with discretion to establish an energy conservation standard for television sets by rule, but does not require such a rulemaking in accordance with a prescribed schedule. 42 U.S.C. 6295(l)(3)

The U.S. DOE conducts technical analysis as part of its appliance efficiency standards program. It undertakes "rulemakings" (the process for setting energy efficiency standards for appliances) for appliances in accordance with a relatively rigid schedule typically requiring rules to be updated every 6 years. Each time the U.S. DOE undertakes a rulemaking process, it broadly describes its analysis process in a Framework Document. Some of the major analysis elements are: Market Assessment Analysis, Engineering Analysis, Life Cycle Cost Analysis, Shipments Analysis, and National Impacts Analysis. Each analysis is presented in detail in a Technical Support Document issued at several stages of the standards rulemaking and in final form along with the Final Rule. Each of these documents, and accompanying spreadsheets, are available on DOE's website .

• **Market Assessment Analysis** – Description of energy efficiency design components and evaluation of their appropriateness for consideration as a minimum efficiency performance standard. Includes analysis of current production of high efficiency equipment, availability of components and impacts on competitiveness. The market assessment analysis is presented in the Technical Support Document.

• **Engineering Analysis** – Assessment of component costs and efficiency impacts. Design options are built up combined optimally to provide an engineering curve relating manufacturer cost to final product efficiency. Summarized inputs and results of the Engineering Analysis are presented in the Technical Support Document. An accompanying Excel spreadsheet is often also provided.

• **Life Cycle Cost Analysis** – Evaluation of benefit vs. cost to consumers for each design option combination. The LCC analysis considers variability in household/businesses in terms of use patterns, energy price and discount rates to generate a distribution of net savings over the useful life of the equipment. The Life Cycle Cost Analysis is presented in the Technical Support Document, along with an Excel spreadsheet detailing the calculations made.

• **Shipments Analysis** – Sub-analysis supporting the national impacts analysis. Shipments (unit sales) are forecast according to historical sales, market share trends and underlying drivers such as new construction and equipment replacements. The Shipments Analysis is presented in the Technical

---

[2] Thanks to Greg Rosenquist, Michael McNeil and Amol Phadke (of LBNL) for their contributions to this section.

[3] For editorial reasons, Part B was re-designated Part A after Part B was repealed by Public Law 109-58.

Support Document, along with an Excel spreadsheet detailing the calculations made. (The Shipments Analysis is contained within the NIA spreadsheet described below)

• **National Impacts Analysis** – The NIA analysis forecasts final and primary energy savings by comparing the total energy of the equipment stock in the policy case vs. the base case. The NIA uses the Shipments analysis as an input and considers efficiency market share shifts as a result of the policy, base case (market-driven) efficiency improvements, growth and turnover of the equipment stock and trends in electricity generation efficiency and delivery. Finally, the NIA evaluates net financial impacts of the standard to consumers due to increased equipment prices and reduced energy bills. The National Impacts Analysis is presented in the Technical Support Document, along with an Excel spreadsheet detailing the calculations made. Utility and Environmental Impacts are generated using DOE's National Energy Modeling System (NEMS). Summaries of these results are generally provided in an Excel spreadsheet.

Comparison of programmes

Table 1 and Table 2 summarize the various programmes around the world.

Table 1: Comparison of current world wide television energy efficiency and energy use programmes.

Country / State	MEPS Programme	Labelling Programme	Test Standard	Details
Table text (Use "Table text" style or Arial 10 justified here)	Table text (Use "Table text" style or Arial 10 justified here)	Egs. Energy Star, Local MEPS etc., Top Runner, Energy Boy Korea, Canada – Energy Star-like		[To be completed]
Australia[4]	Tier I MEPS (1 Star) BEC =127.75 + (0.1825 × screen area) where screen area is in cm^2 and BEC is in kWh/year Energy of model needs to be less than base energy consumption (BEC)	Star Rating Scheme (Each additional star represents a 20% reduction in energy consumption from previous level)	AS/NZS 62087.1:2010 AS/NZS 62087.2.2: 2010	

[4] Data collected from Australian Digital Testing Pty Ltd. September 2010. Personal communication.

Country / State	MEPS Programme	Labelling Programme	Test Standard	Details
California	The California standards apply to TVs with a screen area of less than 1400 square inches (58 in diagonal) are: TIER 1 – effective January 1, 2011: Power ≤ 0.20 * Screen Area (in2) + 32 TIER 2 – effective January 1, 2013: Power ≤ 0.12 * Screen Area (in2) + 25 (similar to Energy Star 4.1)			Active mode standards for televisions larger than 58 inches diagonal are planned to be considered in Phase 2 of the rulemaking. In addition, the standards require that TVs provide a minimum level of brightness in the "home" or default mode in which energy use is measured to prevent TVs being delieverd in modes which are too dim, so that consumers switch to other modes that would erode energy savings. California's 3 watts standby-passive mode power usage standard, in effect since 2006, will be lowered to 1 watt effective January 2011. The standards also require a minimum power factor of 0.9.
Canada	Tier I MEPS: 4W (Standby only)	E Star: 3W (Standby only)	IEC 62087	
China	GB 24850-2010 (December 2010) includes separate efficiency standards for LCD and PDP[5]		GB 12021.7 -1989	
Energy Star 4.1		<275 in^2: PMax = 0.190*A+5, <>275 in^2: PMax = 0.120*A+25		

[5] http://www.powerint.com/blog/mrgreen/china-tunes-new-tv-efficiency-standard

Country / State	MEPS Programme	Labelling Programme	Test Standard	Details
European Union	(2)Ecodesign[6] – Mandatory, effective August 2010. Max on-mode power depending on screen size and whether high definition: (a) 20 watts + A * 1.12 * 4.3224 watts/dm ^{2} (HD) (b) 20 watts + A * 4.3224 watts/dm ^{2}	EU energy label (mandatory) EU Eco-Labelling Programme (voluntary)	EN 50301	
US Federal Trade Commission (FTC)		Has not released a timeline for the proposed television label; Proposed rule: (http://www.ftc.gov/opa/2010/03/tvlabel.shtm)		
Japan	Top Runner Program with penalties if standard not met): Manufacturers and importers to ensure average product efficiency meets standard	National Standard Energy Saving Label (mandatory)	JIS C 6101-1	
United Kingdom[7]		Energy Saving Trust Recommended Products: Voluntary program that recommends the most efficient products in the marketplace Energy Efficiency Index (EEI) of less than or equal to 0.64	IEC 62087	

Table source and notes (Use “Table notes” style or Arial 10 justified here)

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0042:0052:EN:PDF

[7] Data gathered from Energy Saving Trust. September 2010. Personal communication.

Table 2: Comparison of current world wide monitor energy efficiency and energy use programmes.

Country	MEPS Programme	Labelling Programme	Test Standard	Details
Table text (Use "Table text" style or Arial 10 justified here)	Table text (Use "Table text" style or Arial 10 justified here)	Egs. Energy Star, Local MEPS etc., Top Runner, Energy Boy Korea,Canada – EnergyStar-like		
Australia[8]	For Monitors ENERGY STAR 5.0 (effective 2011)	Under Discussion but unlikely to be implemented	US EPA tests	
Canada		ENERGY STAR	US EPA tests	
China	GB 21520-2008, MEPS for LCD monitors: 0.55 (cd/W)	China Mandatory Energy Label: 3 grades based on energy efficiency (cd/W)	CCEC/T23-2003 GB 20943 SJ/T 11292	
Energy Star 5.0		<30 in, <=1.1 megapixels:P_O = 6*(MP) + 0.05*(A) + 3 <30 in, >1.1 megapixels:P_O = 9*(MP) + 0.05*(A) + 3 30-60 in: P_O = 0.27*(A) + 8		
European Union	Ecodesign[9] – Mandatory, effective August 2010. Max on mode power depending on screen size and whether or not high definition: (a) 15 watts + A · 1,12 · 4,3224 watts/dm ^{2} (HD) (b) 15 watts + A · 4,3224 watts/dm ^{2}			
Japan		ENERGY STAR	US ENERGY STAR	

[8] Data collected from Australian Digital Testing Pty Ltd. September 2010. Personal communication.

[9] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0042:0052:EN:PDF.

Challenges faced by television energy use programmes

Convergence: Is a TV a TV?

Convergence manifests itself in two principle ways: (1) convergence of displays and (2) integration of products. This section covers these two forms of convergence. This key points described in this section are, in overview:

1. Convergence: TVs and monitors are converging (TIAX 2008, EU regulation on TVs, Energy Star 2010 etc.). Energy Star will be revising their definitions this year and the issue of whether to combine TVs and monitors will be on the table. In the next five years Energy Star will almost certainly combine TVs and monitors into one definition (Energy Star, personal communication, 2010).

2. IP connectivity: IP connectivity, believed to be a significant factor in convergence between monitors and TVs, is occurring faster than expected with over 50% of TV sold on the US market in 2011 projected to be IP enabled (CEA, 2009 projections and expert opinion) and the same amount globally by the end of 2012 (SID, iSupply, 2010). The function of internet connectivity is popular and much used by those who have it – by 2011 all Vizio TVs (20%+ of the market) will be IPTVs (SID, Vizio, 2010 – presentation entitled “The End of TVs”).

3. TV inputs: modern TVs have similar inputs to monitors and their uses are increasingly similar, with the latest TVs having USB ports, PC inputs, video inputs, Ethernet cable inputs, inputs enabling connection with cameras and MP3 players (e.g. Samsung, Panasonic, Sony etc. 2010). Moreover, the latest display connection technology, HDMI, is expressly designed to work with TVs and monitors – and does not specifically differentiate between the two.

4. Distinguishing features are cheap and easy to change: the features considered by some to distinguish TVs and monitors are easily and cheaply changeable. Tuners and speakers can be, and have in some cases been, externalised – this may even assist manufacturers in designing slimline TVs in accordance with the latest trends (some TVs are under a third of an inch thick);

5. Products already cross the divide: some manufacturers (Samsung and LG) make identical products which they then market separately both as monitors and televisions (Display Search, 2010). Moreover, there exist high quality, high definition monitors sold with the option of purchasing external tuners and external speakers which allow the user to use the product as a television (e.g. JVC). Modern televisions are generally able to be attached to computers and function as monitors.

6. Input connections are not a distinguishing solution: the EU regulation on energy efficiency of TVs defines a TV as a TV “set” or a TV “monitor” – the latter being defined by its input cables. As both computer and TVs’ input connections morph, this is not a sustainable distinction. Moreover, as the Europeans try and regulate monitors, this distinction is causing them issues as they attempt to regulate “monitors” but not TV “monitors”.

Convergence of displays

Over the last twenty years, since the advent of digital television, television technology has developed increasingly rapidly. Developments in monitors and TV displays are closely related, with monitor developments often preceding those with TV displays. Moreover, it is widely recognised that televisions and monitors are increasingly converging (E.g. Energy Star, TIAX 2008 for DOE, EU Regulation on televisions) and relevant modern-day definitions often refer to both. Differences between TVs and monitors tend to be small and are ever decreasing to the extent that some identical products are manufactured and then marketed separately both as monitors and televisions (SID, Display Search, 2010). The main difference between the two is often that TVs contain a tuner (historically costing about $5.50 and projected to cost around $2.50 by the end of this year – Display Search, 2010) and monitors do not.

If monitors and TVs are not distinguishable or a TV is easily modified to become a monitor (by, for example, externalising or simply not using the tuner), then placing them in separate categories creates the potential for loopholes. This section investigates the differences between monitors and TVs concluding that they are few, and none sufficiently significant to warrant separate categories.

Monitors and TVs are becoming increasingly difficult to distinguish and, for the reasons set out in this section, it often makes more sense to speak of displays than it does to distinguish between types of displays.

Are monitors and televisions easily distinguishable?

Differences between TVs and monitors?

The TIAX report (April 2008), prepared for DOE Building Technologies Program, grouped TVs and monitors together under the heading "displays" for the purpose of future projections. For 2006 analysis, however, the report distinguished the two, explaining the differences as follows:

"The 2006 analysis considered monitors independently from TVs and monitors were assumed to go hand in hand with desktop PCs. The basic difference between a TV and a monitor is that a TV has an integrated tuner. Additionally, most TVs have integrated speakers, while monitors generally do not. Also, TVs generally have higher luminance levels (or brightness) because they are generally viewed from greater distances than monitors. In 2020, we foresee a significant overlap between TVs and monitors. The emergence of Internet home video and IPTV, along with handheld PCs, will drive the convergence of the two devices and how they are used in a household. We will still draw a blurred line between the two products for energy consumption calculations, but we have grouped the two in a single "displays" category."

Many of the differences outlined are no longer as relevant as they were in 2006. A significant number of the latest TVs are less than an inch thick. In order to keep TVs displays as flat and slimline as possible, tuners or speakers could easily be externalised, attached either wirelessly or with cables. Models of monitors exist which have high picture quality and have been designed with the possibility of purchasing external tuners and speakers. Moreover, certain manufacturers (Samsung and LG) already make identical products which they market separately both as monitors and televisions (Display Search, 2010).

The EU definition of televisions includes both TV "sets" and TV "monitors" – the distinction between TV "monitors" and other monitors, being based not on tuners but on connection ports. Monitors which have similar input cables to what has been defined as a TV "set", are included in the regulation. With TVs now having input ports similar to monitors and an increasing number of monitors having similar inputs to TVs, this distinction is loosing ground and no longer holds water. Moreover, the division that the Europeans have made between "television sets" and "television monitors" is now causing them significant issues as they attempt to regulate monitors and to distinguish "television monitors" from other types of monitors.

Tuners – the basic difference

Integrated tuners were, historically, said to be the most significant difference. This assumption is now, however, no longer valid:

1. Tuners are extremely cheap components historically costing about $5.50 and projected to cost around $2.50 by the end of this year (Display Search, 2010).

2. Tuners can easily be externalised and would even assist to keep the design of the TV display slim and sleek. Already, when using a set-top box (e.g. cable or satellite box), the TV tuner is not used at all as this functionality is part of the set-top box. Thin display design is increasingly popular with some large displays being less than 1/3 of an inch thick (e.g. Samsung 9000, 55 inch screen size).

3. Monitors already exist with external wired or wireless tuners (e.g. Samsung and JVC)

Integrated speakers

Both wired and wireless external speakers already exist for monitors and TVs, as well as external soundbars (e.g. http://soundbar.com/) and speakers (e.g. http://www.plasma.com/plasmaextras/panasonicspeakers.htm) which can be attached to the displays. In some cases, they are intended to be added to provide sound where the display does not have internal speakers. In most cases, they are intended to provide improved sound quality to the display. They are manufactured by many players including Sony, Panasonic, Samsung, iSymphony etc. As with tuners, the option of externalising speakers can be desirable as it assists in keeping the design of the display slim and sleek.

<u>Products cross the divide</u>

This section describes products currently on the market which cross the divide between televisions and monitors – they fall into 3 broad categories: 1. Identical products which are marketed separately to be sold as TVs or monitors, 2. Monitors which can have additional features attached to turn them into TVs, and 3. Modern TVs which can also be used as monitors and have similar features. TVs and monitors are becoming increasingly similar and difficult to distinguish. A number of displays currently on the market already cross the divide and would be difficult to categorise. The latest TVs have similar features to monitors and can be used as monitors.

Monitors and TVs which are identical

Both Samsung and LG currently manufacture identical products which they then market separately both as monitors and televisions (Display Search, 2010). The marketing is the only difference between the products. This shows how similar the two products are, as well as demonstrating the power of marketing.

Monitors which can be used as TVs

High quality, high definition monitors sold with the option of purchasing external tuners and in some cases external speaker which allow the user to use the product as a television are currently on the market, available for purchase by consumers (e.g. Samsung , JVC). The Samsung P2570HD, for example, comes with an optional “wave bundle”. The additional bundle includes a tuner and the bundled product allows the user to connect to cable, satellite boxes, blue-ray players, gaming systems or computers – like any normal television.

If only TVs with tuners were regulated, it would be easy for manufacturers to externalize tuners, thereby circumventing the rule.

<u>TVs have features traditionally associated with monitors</u>

The latest televisions increasingly have all of the properties of monitors, including a computer input cable which actually allows them to be used as monitors. Many of them are IP enabled, allowing people to surf the internet on their TV. In addition, many new TVs have similar ports and connections to the display as a monitor does. For example, the Samsung 9000 includes 4 HDMI connections, 2 USB ports, 1 component video input, 1 optical sound output, 1 PC input, 1 ethernet, among other. This is now not uncommon. All major manufacturers sell TVs with these capabilities, allowing televisions to be used as monitors, directly attached to a computer or laptop, to view home video content directly from a video camera – or through other means, to view photographs directly from a camera or on a USB stick, as well as accessing the internet, directly though the television. IPTV is key in the convergence and is described in more detail in the next section.

IPTV

IP connectivity, believed to be a significant factor in convergence between monitors and TVs, is occurring faster than expected with over 50% of TV sold on the US market in 2011 projected to be IP enabled (CEA, 2009 and expert opinion). Globally 50% of TVs sold are projected to be IP enabled by the end of 2012 (SID, iSupply, 2010).

Vizio is a significant supplier of TVs to Wallmart. It holds over 20% of the US market. Following the success that Vizio has had with its IP enabled TVs, in 2011, it plans for all of its TVs to be IP enabled.

(SID, Vizio, 2010). Vizio has found the use of the internet extremely popular with those who have purchased TVs with the feature. The results of its survey, extracted from its presentation entitled "The End of Televisions" are set out below.

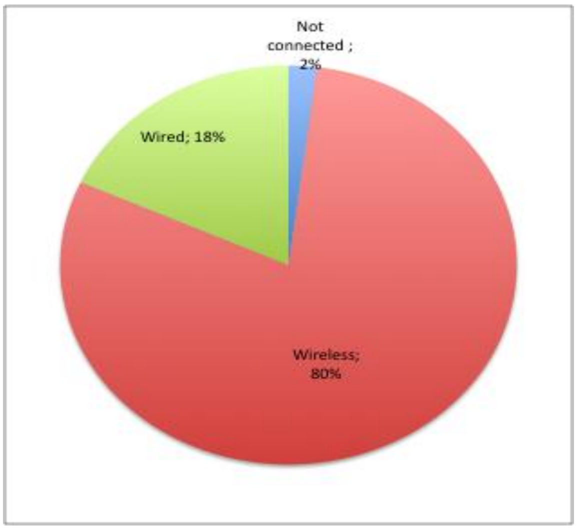


Figure 1. Survey data showing how often Vizio customers with IPTV use the internet through their TVs (Vizio, SID, 2010) – Question "How often do you use VIZIO internet apps?"

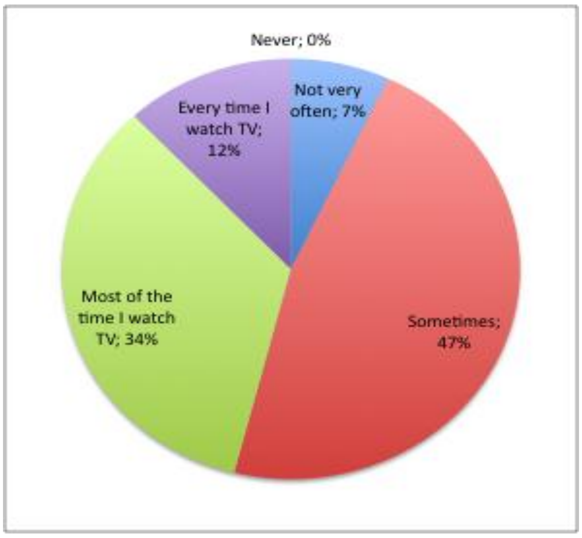


Figure 2. Survey data showing how customers with IPTV connect to the internet through their TVs (SID, 2010)

The cost of adding IPTV to a display is small. Manufacturers will then benefit from additional revenue from "apps" which can be accessed through the internet. In 2011, at least 50% of TVs sold on the US market are projected to be IP enabled (CEA, 2009 projections and expert opinion) and the same amount globally by the end of 2012 (SID, iSupply, 2010).

Connection ports

In developing the definition of televisions for its 2009 regulation, the EU recognised the possibility of loopholes due to convergence between televisions and monitors and included a sub-category of monitors into its definition of TVs. This EU definition of "televisions" includes both television "sets" and television "monitors" – but does not include all monitors. Television "sets" are said to have tuners, whilst television "monitors" do not. The distinction has been made between television and other "monitors" on the basis of the connection ports/input cables. "Television monitors" have similar input cables to what has been defined as a "television set". This definition of "televisions" was developed for a 2009 regulation and reflects the fact that the phenomenon of convergence was already occurring but was not as prevalent as it currently is and will become over the course of the next two years. Moreover, at the time, it was thought that additional energy savings could be made on monitors which were not available from televisions as the former were thought to use significantly less energy than the latter. This is currently less obvious and data suggests that monitors are comparable to more efficient televisions of similar sizes (see section below for further details).

A distinction based on connection ports is, however, unlikely to be an optimal way of avoiding the creation of loopholes. Connection ports can be easily added or taken away from devices at the design stage. More importantly, however, the way televisions have been defined to include certain monitors but not all, now creates an issue for the Europeans in defining and regulating displays and monitors more generally. Had the regulation been developed at a later date, it is unclear whether it would have defined televisions and all monitors together.

Energy consumption of TVs and monitors

There is little data available comparing the energy use of displays used as monitors and those used as televisions. Monitors tend to lead the way in technology which then gets used in television. Accordingly, it was thought that monitors were likely to be able to yield more significant energy efficiency savings than televisions. This, however, may have been a misconception based on a different usage pattern of monitors and the fact that monitors, at that time, typically included newer technology. The current data available for this paper is inconclusive as to which is likely to be more efficient or have greater efficiency potential. In theory, since similar technologies are used for both displays, the potential should be the same.

Data currently available from Ecos (Figure 3), indicates, however, that there is a wide spread of power consumption for monitors and TVs of similar sizes on the market. It is difficult to distinguish a clear pattern – although overall monitors seem to be more efficient than televisions, on average. There are many TVs, however, as or more efficient than monitors, especially at larger screen sizes.

One cause of greater efficiency in LCD displays is the use of LED backlights. Figure 4 indicates that desktop monitors and LCD TVs are likely to have a similar uptake of LED backlit screens.

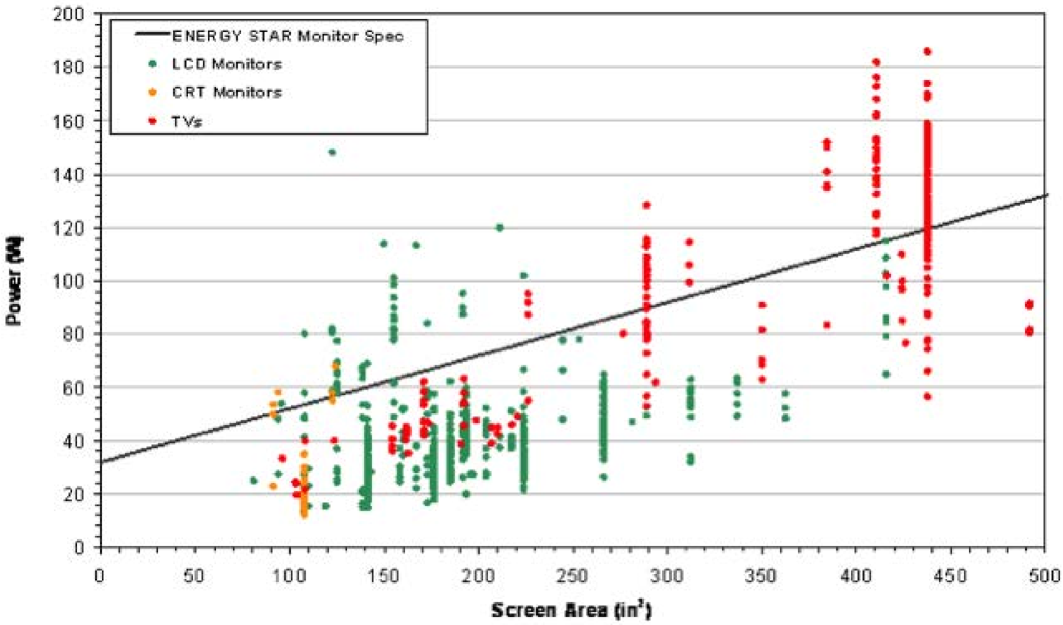


Figure 3. Comparison of power consumption of monitors and TVs by screen size (Ecos consulting, 2010)

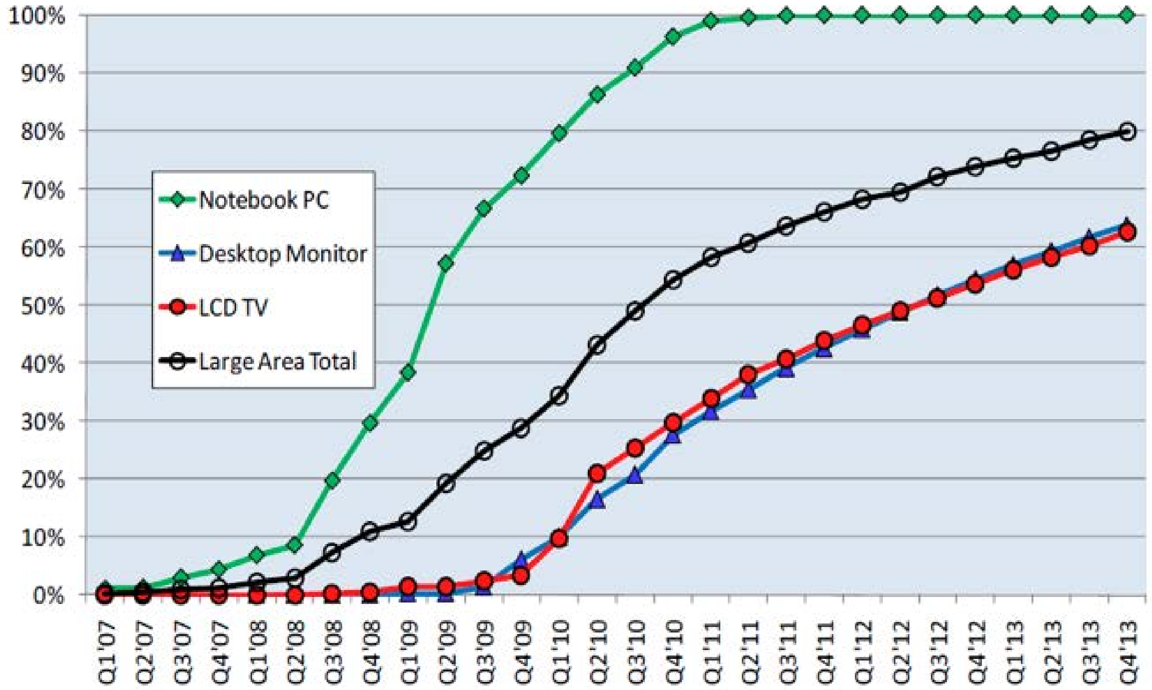


Figure 4. Uptake of LED backlit screens – shows that LCD TV monitors and desktop monitors have similar uptake of LED Backlighting (SID, Display Search 2010)

<u>Product Integration</u>

Product integration is a strong trend across all consumer electronics. It is increasingly difficult to purchase a mobile phone without at least a camera and a music player, not to mention a calendar, internet browsers, email client and the ability to download games and other apps. Similar trends are emerging in TVs. Some consumer electronics which were common-place only a decade ago, have all but disappeared from the market: hi-fi systems, with cassette players, and mini-discs, have disappeared and the overall market for hi-fi systems as we knew them has diminished with, at least the music-playing functionality being taken over by integrated devices including variants on mp3 players.

Convergence, in terms of product integration has been described as bringing together “things that belong together that weren’t” (CES, Worley, Tech Reporter, ABC, 2011). Good convergence has been said to add value: “the whole is greater than the sum of the parts. Pooling efforts creates a better overall experience” (CES, Zuck, ACT, 2011). Convergence is an ecosystem issue comprising both hardware and software issues (CES, Yi, Best Buy, 2011).

TVs are increasingly designed with added functionality. These new designs seem directed at enabling TVs to become the central entertainment system for the household, combining all traditional audiovisual products into one system. Beyond new features such as 3D and internet connectivity which are becoming ubiquitous in new TVs, TVs are also beginning to integrate DVD players and set top box/DVR functionality, as well as the ability to display photos and become a docking station for a music player. Conversely, with TV displays becoming thinner, speakers and other peripherals may be separated from the screen itself. Although sound has traditionally not been a key factor in energy consumption for televisions, with ever-more efficient TVs, it may become a more relevant concern.

The changes in TV design and functionality will have an impact on its future use, and resulting in longer on-times for TVs. This causes 2 types of challenges for regulators – evaluating increases in active mode use of TVs and accounting for energy use of additional features.

Rapidly declining costs

The cost of televisions and other electronics products decline more rapidly than those of traditional electromechanical products. The price of the transistors in one of today's iPods would have been $3.2 million in 1976. That 1976 iPod would have been the size of a school bus and cost around the same as an aircraft carrier today. The cost per transistor has decreased around 20 million times since 1976 (B. Berkoff, SID 2010). The cost reduction factor for the shift from Thin film transistor liquid crystal display (TFT-LCD) to current LCDs is not in the millions. Nonetheless, in recent years, there has been a 20-fold cost reduction at least. In 1999 a 15" LCD monitor cost around $2000. Nowadays a 55" TV can be purchased for around $1000. The cost per watt has also decreased. (B. Berkoff, SID 2010).

Part of the cost declines are attributable to the diminishing amounts of materials used in manufacturing TVs and other electronics. Figures 5 and 6 below show a 2007 and a 2010 46" TV respectively, reflecting a 52% decrease in the mass of the components, 63% reduction in the number of circuit boards and a 55% decline in price despite the shift in technology from CFL to LED backlighting and corresponding increase in energy efficiency. The photos of these TVs manufactured 3 years apart show a large decrease in the volume of material utilized in constructing TVs over the last 3 years. Table 3 further elaborates relevant factors which have decreased over the same time period, including the number of circuit boards. Note that the TVs are not the same brand but are representative of their class. [10]

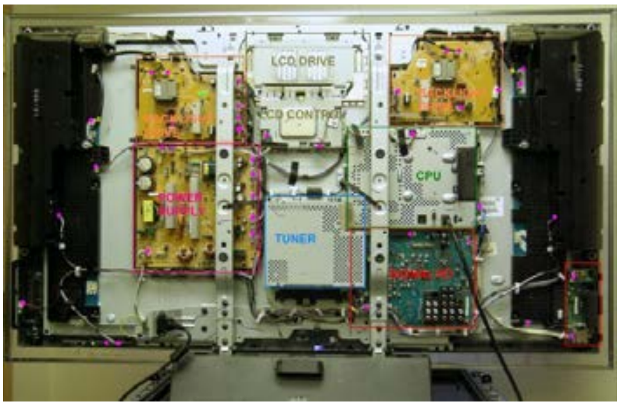


Figure 5. 46" LCD: Sony KDL-46XBR4
Manufactured late 2007 (Photo: Ecos Consulting)

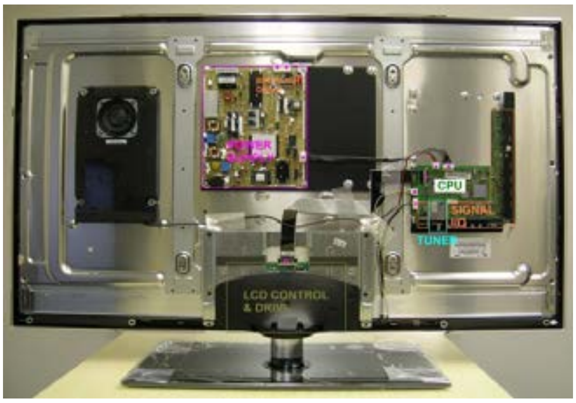


Figure 6. 46" LCD TV: Samsung UN46C5000Q
Manufactured mid 2010 (Photo: Ecos Consulting)

Table 3. Ecos Consulting data showing changes in relevant factors including price over the course of the past 3 years for the televisions pictured in Figures 5 and 6 above.

	2007 LCD	2010 LCD	Change
Backlight Technology	CCFL	LED	
Power	257 watts	50 watts	-80%
Weight	73 lbs	35 lbs	-52%

[10] Photos and table courtesy of Ecos Consulting.

Retail Price	$3,299	$1,499.99	-55%
Number of Connectors	39	9	-77%
Number of Major Circuit Boards	8	3	-63%

This type of rapid change in components and decline in costs present a challenge for technical and impact analyses and need to be taken into consideration in order to ensure meaningful results and enable informed decisions about appropriate standards and labels policies.

International harmonisation

Use of terminology

It is useful to note that in different regions the same terminology is used in different ways. The most confusing word used is “Standard”. In some regions Standard means a measuring method and /or programme requirements as prescribed by a standards body such as IEC, Standards Australia or CEN. In other regions the word standard refers to the programme requirements and the actually testing is referred to as test methods.

This does of course cause a level of confusion. Much is made of working toward international harmonisation for programmes and test methodology. It seem that a good place to start would be to harmonise terminology for programmes nd test methods.

Differences in Metrics

Figure 5 summarizes the MEPS level for various programs. Australia was the first to implement mandatory requirement in Oct 2009. In addition to the differences shown in this diagram there are also differences in the actual units used by differing programmes. For example many of the programmes use a TEC based on usage and screen size, whereas China uses a true efficiency measure of Watts/Cdm2. The appropriateness of the metric, although an important topic, is not discussed here. The point being made is that in this regard there are differences between regions which make objective comparisons of programme effectiveness difficult.

It is clear that these requirements are less sever than the EU MEPS levels. What is equally clear is that as the programmes progress the MEPS levels are becoming rapidly more stringent. By 2013, of the current programmes in existence today, the toughest mandatory programme will be the Californian programme and the toughest voluntary programme will be Energy Star. Most TVs in the US, however, already meet the 2013 California standard.

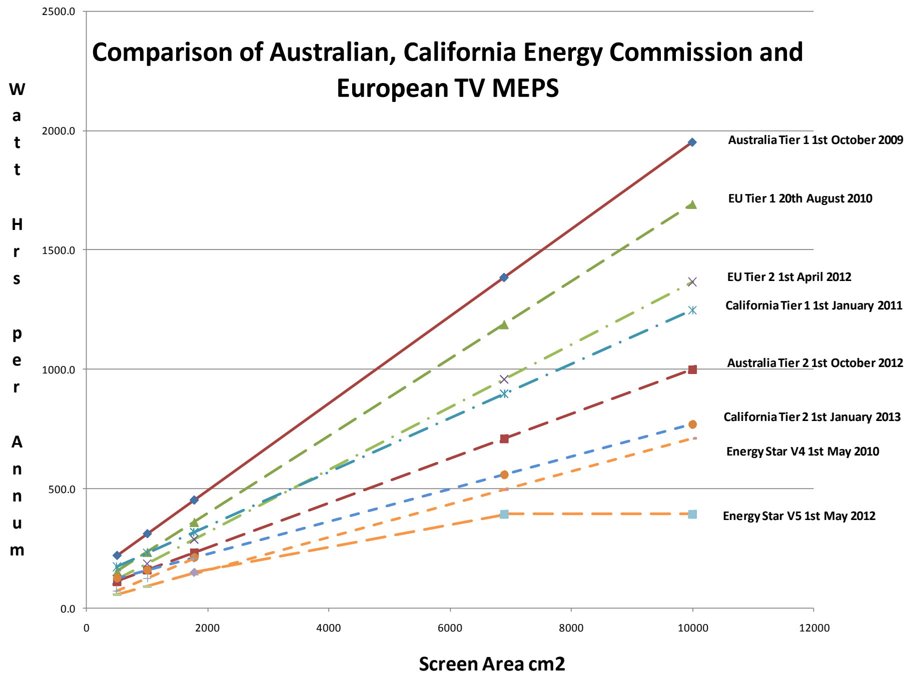


Figure 5.

Comparison of Test Standards Used.

Error! Reference source not found. summarises what measuring standards are used in the various programmes that have been considered in this paper.

Table 3: Comparison of test methods

Programme	Measuring Standard	Comment
EU	IEC 62087 Ed2 Section 11 Broadcast Content Loop	[To be completed]
Energy Star	Test Procedure similar to IEC 62087 Ed2 and used the Broadcast Content Test Loop	
Australia	AS/NZS 62087.1 which is a direct clone of IEC 62087 Ed2 and uses the Broadcast Content Test loops	
Japan	For Plasma and LCD testing is according to IEC 62087 Ed2	
Korea	N/A	
China	Local Standard but uses the IEC Dynamic Broadcast Content Loop.	
CEC	IEC 62087 Ed2 using the Dynamic Broadcast Content Loop	

From the above table it is clear that although there are differences in the various program metrics see Table 1 and Table 2 that there is a high level of harmonisation for the test method. All programmes that measure On Mode power consumption use the IEC Dynamic Video Content Test Loop. Only 2 programmes do not use IEC 62087 Ed2 directly (China and ES), Although ES' method is for all intents and purposes the same as IEC 62087 Ed2.

Sequence of implementation of international standards

[TO BE INSERTED – TABLE OF DIFFERENT STANDARDS AND DIFFERENT DATES – INTERLACED WITH TABLE BELOW FROM ENERGY STAR]

Table Summary of Energy Star Program for TVs

Version	**Created On**	**Effective Date**	**Proportion of Compliance**
Version 3.0	Feb 4, 2008	Tier 1: Nov. 2008; Tier 2: Sep. 1, 2010	
Version 4.0 and 5.0	July 20, 2009	May 1, 2010 (4.0) & May1, 2012 (5.0)	"majority of the market meeting the current Version 4 requirements and more than 25 percent meeting the Version 5 requirements (28.05%)[11]
Version 4.1 and 5.1	April 20, 2010	May 1, 2010 (4.1) & May1, 2012 (5.1)	
Version 4.2	?	April 30, 2011 (?)	
Version 5.3	Jan. 24, 2011	Sep. 30, 2011	
Version 6.012	Scheduled in early 2011	N/A	N/A

Luminance Measurement

As has been discussed many of the current TV programmes have a limit on the luminance ration between "Home" and "Shop" mode. In most programmes this limit is 65%, in Australia it is 50%. Many of the programmes have adopted the 3 bar black and white pattern for this measurement which has a average picture level of 50%. This is considerably higher than the 35% APL that the IEC dynamic broadcast test loop is based on and considerably higher than the Automatic Brightness Limiting (ABL) that is used in Plasma televisions to ensure that the screen phosphors are not damaged.

It seems to the Authors that this issue represents an excellent opportunity for the determination of a suitable pattern that is fair to all technologies and can be adopted internationally.

Trends in television receiver technology

Below is a discussion of the significant technology changes in TV technology and their impact on energy consumption of TVs.

---

[11] Version 5 Data and Analysis, http://www.energystar.gov/index.cfm?c=revisions.television_spec, Retrieved on Feb. 4, 2011; EPA Proposal Memo, http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/television/Televisions_Memo.pdf, Retrieved on Feb. 4, 2011.

[12] Version 5 Data and Analysis, http://www.energystar.gov/index.cfm?c=revisions.television_spec, Retrieved on Feb. 4, 2011.

LED Backlight

The most dominant TV technology in the world today is LCD technology. This technology utlilises a backlight consisting of one of two basic technologies being Cold Cathode Florescent Lights (CCFK) and Light Emitting Diode (LED) technology. LED backlight technology is often promoted as a different technology than LCD. This is not the case as it is merely a form of backlight. The only true LED display technology being developed for TVs is OLED technology and this is discussed further below.

CCFL Backlighting

CCFL has been the mainstay of backlight technology for LCD TVs. As a backlight technology it suffers from a number of drawbacks. The first is that it is difficult to realize a dimmed or modulated backlight on a zone basis. Dimming can be achieved on a full screen or global basis but this provides a limited advantage form both an energy consumption basis and a picture quality basis. CCFLs do have a significant cost advantages for manufacturers but they are rapidly loosing this to various forms of LED backlight technology

Edge Lit LED

Implementation of a full direct or array does represent a significant cost increase for LCD TVs. A compromise is the use of edge lit LED backlights. In this scheme the LEDs on these sets are arranged only along the edge of the LCD panel, and can illuminate the center and other areas of the screen using light guides. This has two consequences. The first is that dimming can only be achieved on a global basis the second is that the light guides cannot distribute the light over the screen in a completely uniform basis. This means that the luminance of the screen will vary according to the point of measurement. This lack of uniformity becomes worse as the screens get bigger. There are now also some examples of limited zone dimming but these are unlikely to perform anywhere near full array LED backlights.

Although edge lit technology achieves significant improvements for energy consumption is does so by limiting the performance of the TV.

Direct (Array or Full)) LED Backlighting

In this scheme the LEDs are arranged as an array behind the LCD panel. Each LED can be independently dimmed which allows for a very fine control of the light through the LCD panel. This achieves significant improvements in contrast ratio at the same time significantly reducing the energy consumption of the LCD TV.

3D

3D technology is rapidly emerging both in terms of broadcast and pre recorded material. In 2010 over 70 movie productions were reported as being filmed in 3D. 3D technology requires two transport streams to be generated from two camera lenses side by side. One transport stream is the right eye of the scene being filmed the other is the left eye.

The 3D capable TVs process each of the transport streams separately and then recombine them using strobe technology. Special glasses need to be worn to view the resultant image. These glasses synchronise with the image on the TV screen shuttering each eye so that the left eye only sees the left eye frames and the right eye only the right eye frames.

The effect of this shuttering is a significant reduction in the effective luminance of the TV. To compensate for this the luminance of the TV is increased and thus the associated energy consumption. It has been estimated that this luminance reduction can be as high as 70-80%. Energy consumption tests on a number of models of 3D TV have varied from an increase of 30 – 100% of energy consumption in 3D mode as opposed to 2D mode.

IPTV and Smart TVs

In the last year or so TVs have emerged that have Internet connectivity. The initial offerings have been limited with access to only predetermined web sites for video content and other material. More recently the term Smart TV has emerged. The term is derived from Smart Phones which have the ability to download and run applications as well as extensive internet functionality. The importance of this technology is that if/when it become widely adopted it has the capacity to change viewing habits and TV usage. The extra processing capability will carry an energy use overhead but the potential for increased viewing times will have significant impact on the annualized TV energy use estimates.

OLED

An organic light emitting diode (OLED) is a (LED) in which the emissive electroluminescence layer is a film of organic compounds. This layer of organic semiconductor material is situated between two electrodes. Generally, at least one of these electrodes is transparent. By arranging these OLEDs into an array a TV display panel can be formed where each element can be separately driven to produce a moving image. TVs with OLED technology have been promised for several years but as yet only limited 11 inch TVs from Sony have been released and these very small TVs are priced at $2999 in Australia[13], a price that is hardly competitive with existing technologies. Reports on the likely energy use of TVs using this technology have also not been positive for first generation product compared to LCD technologies.

Plasma Phosphor

Plasma technology consists of tiny florescent cells that excite red, green and blue phosphors to form colour pixels. Early plasma technology was considered very energy use intensive. Manufacturers have consistently improved the energy use of plasma technology over the last few years by improving the emissivity of the phosphors.

A recent improvement is the use of an additional layer that helps accelerate electron emission. This looks like the best available solution for efficiency improvement in PDPs in the short term.

Plasma still offers excellent picture quality at a very competitive price but is expected to continue to be rated poorly in terms of energy consumption compared to LCD technologies.

Automatic Brightness Limiting

Automatic Brightness Control is a feature that is emerging on televisions where a light sensor is added on ther front of the television which detects the ambient light conditions. The television then adjusts it's luminance level so that the screen is not unnecessarily bright in rooms with low ambient light levels. Where ambient light levels are high, for example, in retail show rooms, the luminance of the television can be adjusted higher to maintain a good picture quality in those environments.

ABC has the potential to offer energy savings by setting lower luminance values in dark or less light rooms. Indeed some manufacturers promote the inclusion of a ABC feature as an eco friendly of , energy efficient feature. The extent that this occurs, however, is not so clear. Analysis of the operation of ABC show a widely varying response with ambient light. Some implementations show little adjustment of the screen luminance until quite low light levels (10-50 Lux) are detected. Others show a gradual reduction of luminance from 200-300 Lux down to less than 10 Lux. (Ref to be added).

Conclusions

A number of complex factors, with varied time horizons, make televisions a challenging product for standards and labeling programmes. These include relatively high innovation, faster time-to-market, and rapid transition from one technology to another. [Summary of key points in paper to be completed]

One of the key challenges of regulating consumer electronics and television in particular, is the combination of the rapid change in technology, markets, usage, infrastructure and costs. Each of these factors develops quickly in comparison to more traditional household products. However, it is the number of changing factors which poses the greatest challenge for policy-makers. In a situation

[13] Smarthouse 17/2/2011

where technology cycles may be significantly shorter than regulatory cycles it may make sense to consider alternatives to traditional separate lengthy rulemaking processes.

Currently, standards and labels are regulated economy by economy with no apparent coordination between their regulatory timetables and approaches, and no consideration of how the standards in one economy impact the products available in another. Despite individual market differences, TVs are globally traded products with similar characteristics, manufactured by a small number of key players. TV regulations, therefore, need to remove the lowest performing products from the markets, whilst encouraging innovation in efficiency. In order to accomplish this goal and keep up with the fast pace of this market, TV regulation could benefit from a more internationally integrated approach. Such an approach would enable relatively rapid updates in MEPS and encourage and promote a consistent stream of energy-efficiency related innovation. In order for such a system to be workable for industry, it would need to promote win-win solutions (such as categorical labeling and incentives for new energy-saving technologies). It would also need to prioritise frequency of updates over stringency and comprehensiveness of standards over perfection.

footnote[14],

References Heading 1 (use “heading 1” style or Arial 12 bold justified here)

References (Use “normal” style or Arial 10 justified here)

Number references in the text in square bracket. Use “references” style here or Arial 10 justified single space. After each reference skip one line (inbuilt into style). See the examples below

[1] Environmental Change Unit. *Domestic Efficient Lighting (DELight)*, University of Oxford (UK), 1998. ISBN 1-874370-20-6.

[14] Use “footnote text’ or Arial 8 justified

Harmonization in Action: The Case of Energy Efficiency Standards in Mexico

Virginie Letschert[1], Michael McNeil[1], Fernando Hernández Pensado[2], Margarito Sánchez Mata[2], Itha Sánchez[3] , Wolfgang Lutz[4]

[1] Lawrence Berkeley National Laboratory, [2] Comisión Nacional del Uso Eficiente de Energía, [3] Instituto de Investigaciones Eléctricas, [4] CLASP

Abstract

The Mexican Government has established a program for the elaboration and revision of Official Mexican Energy Efficiency Standards, for a wide range of equipment and installations. This program is implemented by the National Commission for the Efficient Use of Energy (CONUEE), in the framework of the National Program for Sustainable Use of Energy (PRONASE) of the Mexican Government.

The Collaborative Labeling and Appliance Standards Program (CLASP) and Lawrence Berkeley National Laboratory (LBNL) are collaborating with the Electric Research Institute (IIE) and CONUEE to provide technical support in the development of two minimum efficiency performance standards, for household refrigerators and room air conditioners.

This paper presents the two steps developed by CLASP/LBNL in conducting the project, along with results of the cost-benefit analysis for a standard. Based on desired convergence of test procedures and CONUEE’s current schedule and priorities, potential candidates for harmonization were identified. (1) Then a version of the BUENAS model was customized to include recent appliance data from Mexico, and a prioritization study was carried out based on emission mitigation potential in a harmonization scenario. (2) Once the product was identified, data collection and a cost-benefit analysis were carried out using the Policy Analysis Modeling System spreadsheet tool.

The authors present the Mexican case study as an example of a technical support framework, using a combination of the BUENAS and PAMS tools developed by LBNL and supported by CLASP, to facilitate harmonization of standards as an element of international collaboration to reduce greenhouse gas emission.

Introduction

The Mexican government first implemented minimum efficiency performance standards (MEPS) in 1995 for residential refrigerators, room air conditioners, washing machines and three-phase motors. Since that time the program has been expanded to 24 products in residential, commercial and industrial sectors. In the past, the Mexican appliance standards program has pursued a strategy of ‘harmonization’ with the program administered by the Department of Energy (DOE) in the United States. Harmonization efforts have included using identical or similar test procedures for the rating of products, and equivalent definitions of minimum allowable efficiency. Harmonization has not been complete, due to important differences in product classes sold in the two countries, but efforts to harmonize to the degree possible have been consistent and generally seen to provide a benefit to Mexican appliance manufacturers seeking to meet the requirements of a greater North American market. One specific effort to facilitate this was Mexican (and Canadian) participation in North American Energy Working Group (NAEWG) discussions to identify areas of possible alignment and facilitate their adoption (NAEWG, 2004).

In this paper we try to develop a framework where harmonization is motivated by (1) by a comparison of potential for energy savings, and (2) where the level of the standard is informed by the cost effectiveness of the measure.

The *Bottom Up Energy Analysis System* (BUENAS) is a model built within the LEAP[1] framework that provides estimates of potential energy savings due to standard and labelling (S&L) programs for a wide range of products in the residential and commercial sectors, and industrial electric motors. BUENAS characterizes the potential for many products simultaneously, using estimates of appropriate targets based on international best practices. By comparing impact potential across products, BUENAS allows for setting of program priorities. Once high-priority targets are identified, the *Policy Analysis Modeling System* (PAMS) spreadsheet model compares the impacts of efficiency targets for a single appliance. PAMS not only evaluates the energy impacts of each prospective efficiency target, but also evaluates the cost-effectiveness of each option, thus providing an important selection criterion for policy makers.

Used in combination, the Mexican case study represents an example of a technical support framework to facilitate harmonization of standards as an element of international collaboration to reduce greenhouse gas emissions. In the course of the project, a version of the BUENAS model was customized to include recent appliance data from Mexico, and a prioritization study was carried out based on emission mitigation potential in a harmonization scenario. Once the product was identified, data collection and a cost-benefit analysis were carried out using the Policy Analysis Modeling System spreadsheet tool.

Prioritization of Equipment Types

By default, assumptions and inputs to the BUENAS model for Mexico are those used in the "Global Analysis", documented in "Global Potential of Energy Efficiency Standards and Labeling Programs" (McNeil et al 2008). For this study, some assumptions were modified according to data available in a previous IIE/LBNL analysis of impacts of Mexican standards for refrigerators, air conditioners, motors and washing machines (Sanchez et al. 2006) and additional data provided by CONUEE. Modifications included:

Residential End Uses

- Water heaters and washing machines were added to the analysis, as CONUEE provided data on these appliances.
- Stock and sales calculations from BUENAS are based on macro economic variables. The model was calibrated to CONUEE data for the following end uses: refrigerators, washing machines and lighting.
- Savings potential is modeled as arising from implementation of MEPS. With the exception of the phase out of incandescent lighting, the date of implementation of MEPS is assumed to be 2014. Unless noted otherwise, the base case we assume no improvement of efficiency in absence of standards.

The following table summarizes the assumptions for the base case and efficiency scenarios.

Table 1 Residential End Use Assumption Summary

End Use	Base Case Consumption/Efficiency	Unit	Assumption/ Source	MEPS Level	Unit	Assumption/ Source
Refrigerator	369	kWh	Sanchez, 2006	258	kWh	30% improvement
RAC	2.94	EER	Sanchez, 2006	3.5	EER	15% improvement
Washing Machine	75	kWh	Sanchez, 2006	60	kWh	20% improvement
Water Heater	21	GJ	CONUEE	19	GJ	10% improvement CONUEE internal document
Incandescent Lamps	75% of stock converted to CFLs by 2030	-	LBNL Assumption	5 year Phase out starting in 2012	-	LBNL Assumption
Televisions (LCD)	154	kWh	Energy Star v4 DS, 2010	109	kWh	Energy Star v.5
Televisions (Plasma)	288	kWh	Energy Star v4 DS, 2010	203	kWh	Energy Star v.5
Standby Power	24.1	kWh	IIE 2008	6.55	kWh	1W standard IIE 2008

[1] The *Long Range Energy Alternatives Planning System* is a product of the Stockholm Environment Institute. More information about the LEAP platform may be found at http://www.energycommunity.org/default.asp?action=47

Commercial End Uses

Commercial end uses are potentially big energy consumers, and offer the possibility for large savings. According to the current analysis, Mexico could save 19 TWh of electricity from commercial lighting, space cooling and refrigeration, compared to 17 TWh from the residential sector. A significant savings is expected from the commercial sector in Mexico because this is a large part of the Mexican economy, and because savings potential is relatively untapped compared to the residential sector. However, assumptions in this sector are more crude than in the residential sector and data is sparse.

BUENAS estimates 22.6 million employees in the service sector in 2004 in Mexico. A recent report estimated this at 15.8 million in 2004 (Molina Center). In BUENAS, floor space was scaled accordingly. With this correction, BUENAS gives an estimate of 12.99 TWh for the three main end uses (lighting, space cooling and refrigeration). Current electricity sales to the commercial sector are 13.0 TWh (2005, source SENER). This indicates a slight overestimate by BUENAS since, while the three main enduses should account for the majority of end uses[2], there is a significant contribution from ventilation, office products, and other uses..

Motors

Three-phase electric motors are modeled as a constant fraction of industrial electricity, which in turn grows with growth of the industry sector. In the formula below, $GDPVA_{IND}$ is national GDP times the fraction of the economy in the industry sector, which was 26% in Mexico in 2005, according to the World Bank. The ratio ε relating electricity consumption to value added GDP is 0.35 kWh per dollar, from IEA. Finally, the percentage of industrial electricity *p* is assumed to be 49%[3].

$$Elec(y) = GDPVA_{IND}(y) \times \varepsilon \times p$$

Baseline and target efficiencies for industrial motors are based on current standards and target setting according to the next efficiency level within prevailing labeling schemes. For Mexico, the baseline is assumed to be at the current standard, while the target efficiency is assumed to match current standards in the U.S. The resulting weighted average baseline efficiency for motors is 90.6 percent and the target efficiency is 92.6 percent.

---

[2] Another potential source of error would be if any of the firms included in the “empresa mediana” category are actually commercial sector businesses.

[3] Data on fraction of industrial electricity from motors were not available. Brazil is used as a proxy (Geller 1991)

Table 2 BUENAS Results Summary for Mexican Appliances – Annual Values

	2005			2020						2030					
	Demand	Share	Emissions	Demand	Share	Growth	Savings	Savings	Savings	Demand	Share	Growth	Savings	Savings	Savings
End Use	TWh	%	mt CO2	TWh	%	%	TWh	%	mt CO2	TWh	%	%	TWh	%	mt CO2
Commercial Lighting	6.84	50.5%	4.60	15.44	48.7%	5.6%	3.23	20.9%	2.12	27.64	46.8%	5.7%	9.48	0.34	6.12
Commercial Refrigeration	1.71	12.7%	1.15	3.70	11.7%	5.3%	0.67	18.2%	0.44	6.49	11.0%	5.5%	1.64	0.25	1.06
Commercial Space Cooling	5.00	36.9%	3.36	12.56	39.6%	6.3%	2.43	19.4%	1.60	24.90	42.2%	6.6%	7.88	0.32	5.08
Total Commercial	13.55	100.0%	9.11	31.70	100.0%	5.8%	6.34	58.5%	4.16	59.03	100.0%	6.1%	19.00	91.3%	12.26
Room AC	7.89	24.7%	5.31	14.89	30.2%	4.3%	1.74	11.7%	1.14	26.30	39.2%	4.9%	4.39	16.7%	2.83
Central AC	0.14	0.4%	0.10	0.50	1.0%	8.7%	0.01	1.4%	0.00	0.71	1.1%	6.6%	0.02	2.7%	0.01
Fans	2.39	7.5%	1.61	2.88	5.8%	1.3%	0.73	25.3%	0.48	3.09	4.6%	1.0%	1.19	38.5%	0.77
Incandescent Lamps	6.22	19.5%	4.19	6.05	12.3%	-0.2%	3.87	64.0%	2.54	4.08	6.1%	-1.7%	1.07	26.3%	0.69
Fluorescent Ballasts	0.49	1.5%	0.33	0.87	1.8%	3.9%	0.10	11.4%	0.07	1.20	1.8%	3.7%	0.25	20.5%	0.16
Refrigerators	5.90	18.5%	3.97	8.75	17.8%	2.7%	0.97	11.1%	0.64	10.25	15.3%	2.2%	2.19	21.4%	1.41
Standby Power	1.50	4.7%	1.01	2.19	4.4%	2.5%	1.01	46.3%	0.66	2.74	4.1%	2.4%	1.60	58.5%	1.03
CRT Televisions	4.82	15.1%	3.24	0.60	1.2%	-13.0%	0.00	0.0%	0.00	0.00	0.0%	-26.0%	0.00	0.0%	0.00
LCD Televisions	0.04	0.1%	0.03	7.81	15.8%	42.2%	1.75	22.4%	1.15	13.14	19.6%	26.1%	3.88	29.5%	2.50
Plasma Televisions	0.03	0.1%	0.02	0.97	2.0%	25.3%	0.16	16.4%	0.10	0.72	1.1%	13.2%	0.21	29.4%	0.14
Washing Machines	1.17	3.7%	0.79	1.53	3.1%	1.8%	0.17	11.4%	0.11	1.70	2.5%	1.5%	0.33	19.7%	0.22
Water Heaters	1.33	4.2%	0.27	2.24	4.5%	3.5%	0.19	8.5%	0.04	3.08	4.6%	3.4%	0.47	15.3%	0.10
Total Residential	31.93	100%	20.85	49.28	100%	2.9%	10.70	22%	6.93	67.00	100%	3.0%	15.61	23%	9.86
Total Buildings	**45.48**	**100%**	**46.08**	**80.98**	**100%**	**3.9%**	**17.04**	**21%**	**11.09**	**126.0**	**100%**	**14.3%**	**34.6**	**27%**	**22.1**
Motors	46.69	100%	31.41	81.53	100%	3.8%	0.81	1.0%	0.53	113.3	100%	3.6%	2.05	1.8%	1.32
Total All Sectors	**92.17**	**100%**	**77.48**	**162.50**	**100%**	**3.9%**	**17.85**	**11%**	**11.62**	**239.3**	**100%**	**3.9%**	**36.7**	**15%**	**23.4**

Note: Carbon savings use a carbon factor value of 0.667 in 2010. The carbon factor forecast was trended according to the forecast in IEA's World Energy Outlook. Extrapolated in this way, the electricity carbon factor is 0.656 kg/kWh in 2020 and 0.645 kg/kWh by 2030.

Results

The results variables are:

- *Energy demand* – Energy used by each end use in the Business as Usual case (Base Case) in 2005, 2020 and 2030.
- *Energy share* – Energy used by each end use as a fraction of total modeled end uses. This is not normalized to a forecast of total energy use in each sector, since a baseline is not provided.
- *Growth* –average annual energy growth of each end use between 2005-2020 and 2005-2030.
- *Savings* – difference in energy consumption between BAU and efficiency case.
- *Savings %* - percentage decrease in energy consumption for each end use.

Because of the historical alignment between U.S. and Mexican refrigerator and room air conditioner standards, and the opportunity presented by an upcoming revision of the U.S. standards for these products, CONUEE had a strong interest in these products. The BUENAS results show that in terms of energy savings in 2030, these two products rank highly among residential products – first for room air conditioners and third for refrigerators with 4.39 and 2.19 TWh respectively. LCD televisions are second in priority, with 3.88 TWh savings. This product has never been subject to MEPS in the United States, but a rulemaking covering them is expected in the next year or two. CONUEE therefore expressed an interest in coordinating closely with that rulemaking as it progresses, and focus on the other two appliances in the short term.

The results also indicate a large opportunity for energy savings in the commercial sector. In fact, commercial sector savings could exceed those of the residential sector. Harmonization schemes or other acceleration of standards will likely take longer to implement for these end uses due to the scarcity of data and relative lack of experience in regulating these products. The analysis indicates, however, that further investigation and data collection for these products is warranted from an energy savings perspective.

Cost Benefit Analysis

Both refrigerators and room air conditioners were the subject of cost-benefit analysis, but the room air conditioner results were not available for publication at the time of this study; therefore we focus on refrigerators here. In order to evaluate the cost effectiveness of various refrigerator design options, we utilize CLASP/LBNL's Policy Analysis Modeling System (PAMS). PAMS is a spreadsheet model designed to analyze cost-benefit and national impacts of minimum efficiency performance standards (MEPS) for a different appliances, in a wide range of national contexts. For this analysis, LBNL developed a customized version of PAMS applied to CONUEE's refrigerator standards program. In this section, we present the cost benefit analysis of a potential update of the current standard for refrigerator-freezers (NOM015-ENER-2002) to take effect on January 1, 2015, that is, with one year delay after implementation of the U.S. standard. The analysis focuses on the four major product classes (PC) sold in Mexico (they represent 98% of the market in 2010):

- PC1. Refrigerators and refrigerator-freezers with manual defrost.
- PC3 Refrigerator-freezers—automatic defrost with top-mounted freezer without an automatic icemaker
- PC7 Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service (TTD)
- PC11. Compact refrigerators and refrigerator-freezers with manual defrost.

Inputs for PAMS

The following data were derived from Mexican sources as part of the harmonization study. In cases where local data were not available, LBNL used DOE's assumption/data as a proxy (USDOE, 2010).

Market Data and Sales Forecast

The manufacturer association for refrigerators ANFAD provided data and their forecasted sales between 1990 and 2016 and market shares between 2004 and 2010. Top mount refrigerator-freezers dominate the market with more than 80% of market share.

PAMS uses a macroeconomic model to forecast sales of appliances (McNeil, 2010) that was used in order to predict the sales after 2016. ANFAD forecast a 3% growth rate to 2016 and PAMS a 1.5% growth rate after that year. The product class market shares are held constant after 2010.The following graph represents the historical and projected sales by product class.

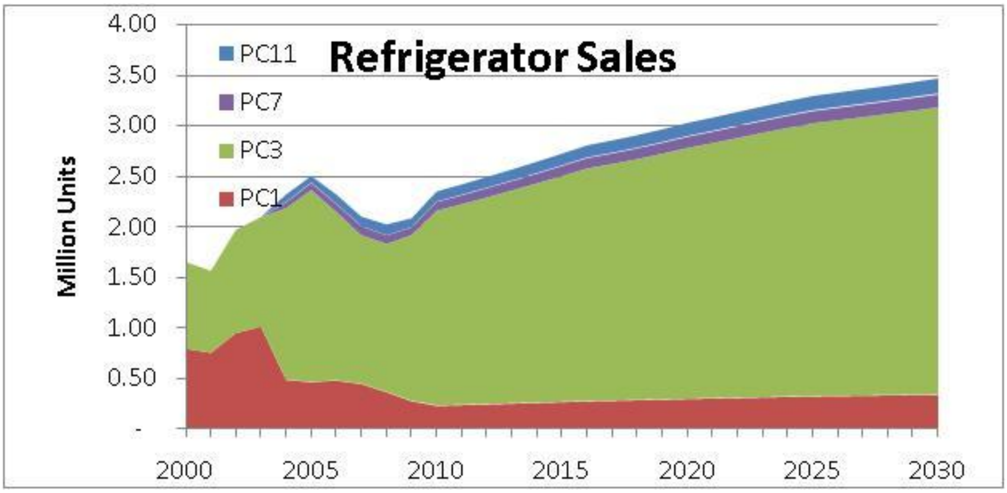


Figure 1 Historical and Projected Sales of Refrigerators by Product Class.

Efficiency trends are based on historical certification data provided by ANCE an independent certification laboratory. The following figure presents the historical tested energy consumption by product class:

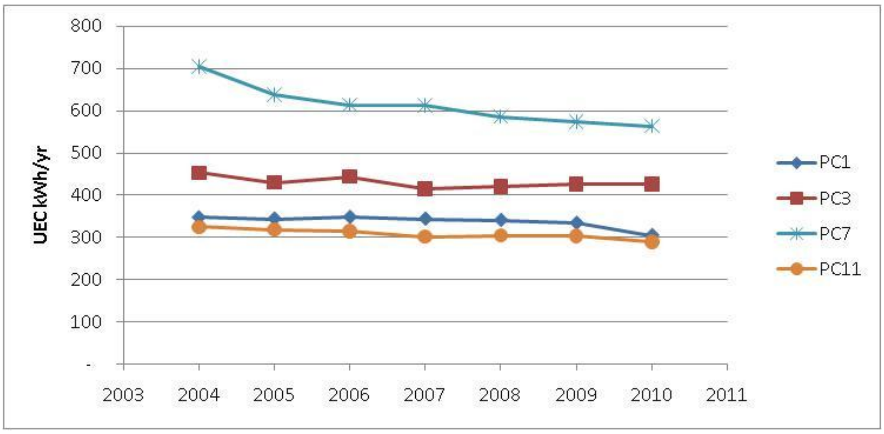


Figure 2 Energy Consumption trends

We can see that every product class has different trends in energy efficiency. We calculate the 2006-2010 growth rate, assuming that in the years after the last standard took effect (2003) the market is affected by the regulation and we don't include it when determining our business as usual after 2010. For PC7 only we make a correction, using DOE's assumption of efficiency trends because the side by side refrigerators sold in Mexico and the US should be the same or very similar. For PC3, the UEC seems to go up in the latest years. We figure that the efficiency gains are probably offset by the volume going up. Because it is difficult to disentangle the two effects, we assume that the UEC is constant after 2010.

DOE has revised its test procedure for refrigerators (DOE,2011), and we assume that Mexico will revise their test procedure accordingly. As a consequence we adjust the forecasted UEC by the "Energy Standard Adjustment Factor" (ESAF). The new test procedure includes modified compartment temperatures and take in account the ice making, so the UECs are going up when the ESAF is applied. The ESAF is discussed in detail in the DOE technical support document (DOE, 2010).

Table 3 Efficiency trends and Energy Use Inputs

	UEC (old TP)	**Annual Efficiency Improvement**	**Forecasted UEC**	**UEC (New TP)**
	2010	**2006-2010**	**2015**	**2015**
	kWh	*%*	*kWh*	*kWh*
PC1	334*	1.4%	308	346
PC3	427	0%	427	480
PC7	564	0.8%	542	702
PC11	304*	1.1%	285	321

*2009 value

Engineering Data

In order to determine which levels of efficiency have a positive impact on consumers, we need to evaluate the incremental equipment cost for each level of target efficiency. Therefore, we use a cost curve that describes the relationship between efficiency and the cost of components. Because such data could not be generated by stakeholders in Mexico, we have to use another country as a model. The U.S. is the ideal candidate because:

- Over one third of the U.S. refrigerators imports are from Mexico (USDOE, 2010), so it is reasonable to assume that the models are similar in both countries
- Mexico and the U.S. have the same baseline defined by the standard NOM015-ENER-2002

- In order to confirm that the costs and efficiencies identified in the DOE analysis can be made possible in the Mexican context.

Cost vs efficiency data are available in the DOE technical support document for product classes 3.7 and 11. To represent PC1, we use PC11 because they are the most similar in design (one door and no automatic defrost). While compact models analyzed by the DOE are significantly smaller than those sold in Mexico, among the available data PC11 seems the most suitable to represent PC1. DOE has not found consistent differences on the incremental costs for different volumes (Appendix 5, DOE, 2010). In the end it was assumed that there is no relationship between volumes and incremental costs.

The cost curves from DOE are combined with the retail prices found in Mexico in order to generate new curves. Also manufacturers have commented that incremental prices from DOE should be inflated by 5%.

The following table presents the retail prices in Mexico:

Table 4 Retail Prices in Mexico

Product Class	Average Price
Refrigerators and refrigerator-freezers with manual defrost	253 *2010$*
Top-mount refrigerator-freezer	579 *2010$*
Side-by-side refrigerator-freezer with TTD	1930 *2010$*
Compact refrigerators and refrigerator-freezers with manual defrost	232 *2010$*

The following graph illustrates the adjustment made for PC3 as an example:

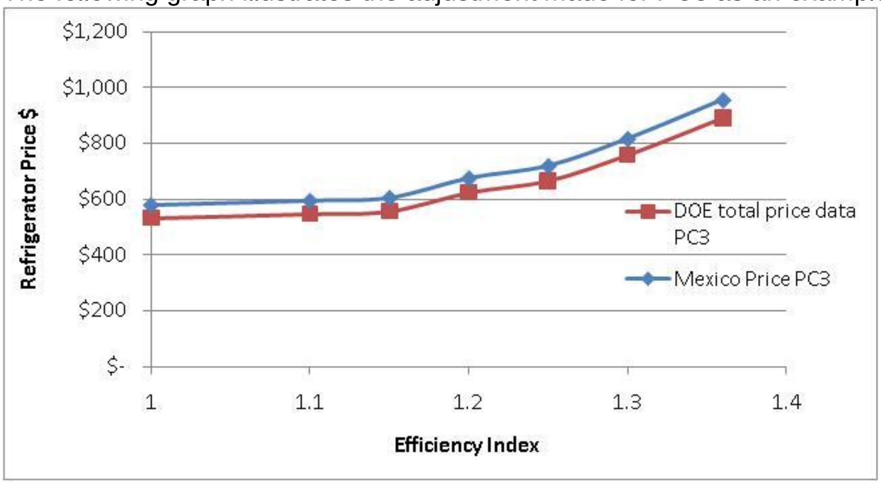


Figure 3 Cost Curves adjustment for PC3

Energy/Economy Sector Data

Table 5 Summary of Economic and Energy Sector data inputs:

Input		Average Value	Acronym	Source/Assumption
Energy prices		7 cts per kWh		Comisión Federal de Electricidad (CFE)
Energy price trend		1.6% per year		CFE
Consumer Discount rate		3.8%	DR	IN
National Discount Rate		4.5%	DR_N	CETES
Heat Rate		2.0	HR	CFE
Transmission and Distribution losses		17%	TD	CFE
CO2 emission factor		0.667 kg/kWh	EF	CONUEE
Lifetime	Two-Door	15 years	L	IIE
	One Door	10 years		Evidence from US market (DOE,2010)

Results

Life Cycle Cost

The Life-Cycle Cost (LCC) of the equipment accounts for all expenditures associated with purchase and use over the lifetime (L) of the appliance. The two main components of Life-Cycle Cost are the equipment cost (EC) and the operating cost (OC). Equipment cost is the retail price paid by the consumer purchasing the appliance. Operating cost is the cost of energy for using the equipment. The savings that occur in the future are discounted with the appropriate consumer discount rate (DR).

Life-Cycle Cost is given by $$LCC = EC + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

We only show the results for the main product classes: one door refrigerator or refrigerator freezer and two door, top mount refrigerator freezers. A negative LCC means that the consumer will enjoy savings from the measure, and positive LCC means that the consumer won't recover his or her initial investment.

Table 6 Life cycle cost results for PC1

	PC1				
	Efficiency Index	**Incremental Cost**	**UEC**	**LCC**	**LCC Savings**
		USD	**kWh**	**USD**	**USD**
No MEPS	1.17		346	$508	
Design option 1	**1.20**	**$ 6**	**337**	**$505**	**$(3)**
Design option 2	1.25	$11	324	$508	$ 0
Design option 3	1.30	$17	311	$509	$ 1
Design option 4	1.35	$31	300	$528	$20
Design option 5	1.40	$41	289	$529	$21
Design option 6	1.45	$71	279	$555	$48
Design option 7	1.50	$79	270	$567	$59
Design option 8	1.59	$115	254	$623	$115

Table 7 Life cycle cost results for PC3

	PC3				
	Efficiency Index	Incremental Cost	UEC	LCC	LCC Savings
		USD	kWh	USD	USD
No MEPS	1.06		480	$1,083	
Design option 1	1.10	$16	462	$1,071	$(12)
Design option 2	1.15	$26	442	$1,060	$(23)
Design option 3	1.20	$96	424	$1,110	$27
Design option 4	**1.25**	$141	407	$1,136	$53
Design option 5	1.30	$238	391	$1,215	$132
Design option 6	1.36	$377	374	$1,334	$251

National Impacts Analysis

In addition to cost-benefit analysis to individual consumers, the PAMS model also forecasts impacts of each MEPS option on the national level in each year from 2015 to 2030. There are five main results of the national impacts analysis:

- National Energy Savings (NES) – The amount of site electricity demand avoided through introduction of higher efficiency refrigerators. It is given by the difference of national energy consumption (NEC) in the base case (BC) and the standard case (SC).

  With NEC given by: $NEC(y) = \sum_{age} Stock(y, age) \times UEC(y - age)$

- National Source Energy Savings (NES_{source}) – The amount of source energy saved through the standard program (primary energy):

$$NES_{source} = \frac{NES}{1+TD} \times HR$$

- Net Present Value (NPV)– Net financial savings of operating cost (ΔNOC) and increased equipment costs (ΔNEqC), discounted to the present year (2010) using a national DR_N..

$$NPV = \sum_{y} (\Delta NOC(y) - \Delta NEqC(y)) * (1 + DR_N)^{-(y-y_0)}$$

- Environmental Impacts – Reduction of emissions of carbon dioxide (CO_2em) resulting from reduced electricity consumption.

$$CO_2em = \frac{NES}{1+TD} \times CF$$

- Avoided Generation Capacity (Q_{sav}) – Reduction in peak-load power demand and power plant construction[4].

$$Q_{sav}(y) = \frac{NES(y)}{(1+TD) \times hrs / year}$$

[4] This calculation assumes a flat load for refrigerators.

The following graph illustrates the annual cost savings of the MEPS for PC3 for a 25% efficiency improvement. We can see that the cost exceed the savings in every year of the program.

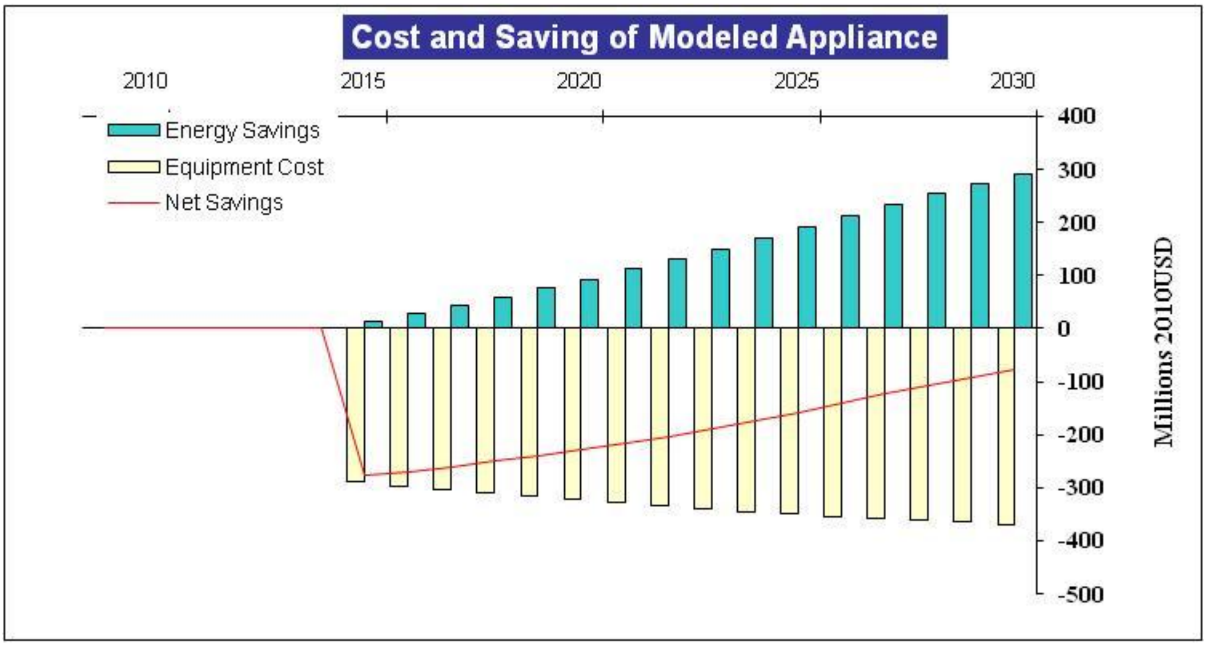


Figure 4 Annual Cost and Savings for PC3

In order to look at the effect of the standard over the whole market of refrigerators, we gather the results initially given by product class into groups. We define groups based on three criteria and create three scenarios S:

- S1: Harmonization with the new US standard
- S2: Maximum Cost effective measures
- S3: Maximum Energy Savings with a positive NPV.

The following table presents the efficiency levels that correspond to each scenario, along with the LCC associated to them:

Table 8 Efficiency targets and LCC in each scenario

	S1		S2		S3	
Product Class	**Efficiency Index**	**LCC Savings ($)**	**Efficiency Index**	**LCC Savings ($)**	**Efficiency Index**	**LCC Savings ($)**
PC1	1.20	$ 2.6	1.20	$ 2.6	1.20	$ 2.6
PC3	1.25	$ (52.8)	1.15	$ 23.0	1.15	$ 23.0
PC7	1.25	$ (28.8)	1.15	$ 12.1	1.20	$ 11.3
PC11	1.25	$ 2.5	1.20	$ 5.2	1.30	$ 1.5

The following conclusions can be drawn from the table:

- Harmonizing Mexican MEPS with current U.S. MEPS would be cost-effective for single-door classes 1 and 11.
- Harmonizing Mexican MEPS with current U.S. MEPS would NOT be cost-effective for two-door classes 3 and 7.
- A cost-effective level exists for two-door classes with an efficiency improvement of 15% and 20% for classes 3 and 7, respectively.
- A cost-effective efficiency level exists for side-by-side class 11 which exceeds the U.S. MEPS level, with an efficiency improvement of 30%

The following table summarizes the national results in each scenario:

Table 9 National Impact in every scenario

	Product Class	NES (GWh) 2015-2030	Source Savings (Mtoe) 2015-2030	Equipment Cost (M$)	Energy Savings (M$)	NPV (M$)	CO_2em Savings 2015-2030	Avoided Capacity 2030
S 1	PC1	262	0.1	$ 11	$18	$ 7	0	8
	PC3	23,309	4.8	$ 3,097	$1,842	$(1,255)	19	627
	PC7	944	0.2	$ 113	$72	$ (41)	1	33
	PC11	869	0.2	$ 52	$58	$ 6	1	28
	Total	25,384	5.2	$ 3,273	$1,990	$(1,283)	20	697
S 2	PC1	262	0.1	$ 11	$18	$ 7	0	8
	PC3	12,001	2.5	$ 393	$ 948	$ 555	10	323
	PC7	250	0.1	$8	$20	$ 12	0	10
	PC11	493	0.1	$ 19	$33	$ 14	0	16
	Total	13,006	2.7	$ 430	$1,019	$ 588	10	357
S 3	PC1	262	0.1	$ 11	$18	$ 7	0	8
	PC3	12,001	2.5	$ 393	$ 948	$ 555	10	323
	PC7	636	0.1	$ 40	$50	$ 9	1	24
	PC11	1,215	0.3	$ 79	$81	$ 3	1	40
	Total	14,113	2.9	$ 523	$1,097	$ 574	11	395

Some comments are in order about the result that a MEPS harmonized with the recent DOE MEPS would not be cost effective for the major Mexican product class. The difference in cost-effectiveness between product class 3 in the two markets can be explained by several factors:

- *Electricity Prices* - In Mexico, electricity prices are subsidized, and about half of what they are in the US
- *Incremental Costs Relative to Volume* - US refrigerators have a bigger capacity (60% higher), so they consume more and the incremental costs haven't been found to be a function of volume by DOE (see Appendix 5A of TSD for examples). As a consequence larger refrigerators have a relative advantage compared to smaller refrigerators, using DOE data.
- *Higher Manufacturer Costs* – Production costs taken from the U.S. market were adjusted upward by 5% for Mexico based on inputs from Mexican manufacturers, even though the refrigerators manufactured are smaller than in the US.

Conclusion

Several conclusions can be drawn from the study presented in this paper. In a general way, the study demonstrates the application of a *system* of policy analysis tools in support of a national standards and labeling program. The first tool, BUENAS is applied to the question of CONUEE's priorities and the value of harmonization relative to focus on other products. The model results largely confirm the appropriateness of a priority on refrigerator and air conditioner harmonization, while also indicating that further investigation into setting standards for commercial building equipment is warranted. Once priorities are confirmed, the PAMS tool provides a complete and robust analysis of the likely impacts of various MEPS scenarios for refrigerators, including the harmonization scenario. The analysis finds that the MEPS proposed in the United States may not be cost effective to Mexican consumers for the most important product class. Cost-benefit analysis should be an important consideration in any mandatory efficiency standard. Further actions that may be indicated from this result include (1) consideration of alternative efficiency target levels (2) further investigation of manufacturing costs in Mexico and their dependence on specifics of Mexican products (such as size) and (3) postponement of phasing of harmonization until technology costs are found to decrease, due for example to economies of scale in the U.S. market.

References

[1] McNeil et al, Global Potential of Energy Efficiency Standards and Labeling Programs, for CLASP, 2008.

[2] McNeil, Letschert, Modelling diffusion of electrical appliances in the residential sector, Energy and Buildings, Volume 42, Issue 6, June 2010, Pages 783-790, ISSN 0378-7788.

[3] NAEWG (2004).North American Energy Efficiency Standards and Labeling, North American Energy Working Group (NAEWG), Energy Efficiency Expert Group.

[4] USDOE, Notice of Proposed Rulemaking Technical Support Document, Washington D.C , september 2010. Available at: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/refrig_nopr_tsd_201-09-23.pdf

[5] Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers: Final Rule and Interim Final Rule, *Federal Register*, 75 FR 78810, December 16, 2010

[6] Norma Oficial Mexicana NOM-015-ENER-2002, Eficiencia energética de refrigeradores y congeladores electrodomésticos. Límites, métodos de prueba y etiquetado

[7] PAMS, user guide and methodology document. Available at: http://www.clasponline.org/clasp.online.resource.php?disdoc=285&pc=1

[8] Sanchez et al., Assessment of the impact of standards and labeling programs in Mexico (Four Products), 2006

[9] Geller, H. S. (1991). Efficient Electricity Use - A development Strategy for Brazil, ACEEE.

Learning from the Best: The Potential for Energy Savings from Upward Alignment of Equipment Energy Efficiency Requirements?

Paul Waide[a], Lloyd Harrington[b] and Michael Scholand[c]

[a]Navigant Consulting Europe

[b]Energy Efficiency Strategies

[c]N14 Energy

Abstract

This paper reports findings from an extensive investigation of the energy efficiency standards and labelling programs in place in China, the EU, India, Japan and the USA. It identifies what might be gained through closer coordination and alignment of technical requirements and policy settings among the major economies and explores what additional energy and carbon savings could be realized were economies to extend the coverage and stringency of their programs to align with international best practice. The paper summarizes key results for each of the most significant end-uses in the residential, commercial and industrial sectors and gives examples of the types of savings that might accrue were the ambition and coverage of existing programs to be raised in line with current international best practice.

It estimates that the annual global CO2 savings potential in 2030 from best practice policy harmonisation for equipment energy efficiency standards is about 8% of all energy-sector emissions and that universal adoption of the current most ambitious measures would save annually:

- 4000 TWh of final electricity demand and 45Mtoe of oil and gas demand in the residential, commercial and industrial sectors excluding energy used for transport and industrial process heat
- 2600 Mt of CO2 emissions

Introduction

Among the world's major economies there is common agreement on the effectiveness and value of energy labelling and minimum efficiency standards as policy instruments to improve equipment energy efficiency; however, there has been relatively little attempt to learn from each other in the design of these schemes. As a result standards and labelling energy efficiency thresholds are set at quite different levels such that some economies may lead the way in the ambition of the regulations for some equipment yet lag behind in those of others. Although policymakers in the major economies are increasingly aware of the programmes in place in peer economies only limited information about those programmes finds its way into domestic programme design processes and international alignment of policy settings remains ad hoc and limited. This is surprising given the potential benefits of greater cooperation. Closer alignment of equipment energy using test procedures and energy performance metrics would facilitate trade, conformity assessment and comparison of policy settings across the major economies. More importantly it could also facilitate greater energy savings.

This paper reports some of the findings of a new study [1], conducted by Navigant Consulting with support from Energy Efficient Strategies and commissioned by the Collaborative Labelling and Appliance Standards Program, that considers the situation applying in the five major economies of China, the EU, India, Japan and the USA. The study examined 24 major electric end-uses[1] in each of the economies and assesses:

- The characteristics and similarity of energy performance test procedures and the prospects for greater international alignment or harmonisation
- The characteristics and similarity of energy efficiency metrics used in standards and labelling schemes and the extent of comparability between them
- Similarities and differences in product classifications
- The extent of coverage of energy efficiency standards and labelling schemes
- The ambition and stringency of the schemes
- Initial estimates of the potential to increase savings through harmonisation of requirements aimed at today's most efficient level.

This paper reports a summary of some of the key findings regarding test procedures and presents illustrations of the differences that product policy coverage and policy ambition have on savings. It begins by considering the conceptual issues underpinning harmonisation and the degree to which they may influence future cooperative thinking.

The world of standards and labelling

Most of the world's more advanced economies employ minimum energy performance standards (MEPS) and labelling schemes for energy using equipment. Currently these are in place for a variety of end-use equipment types in countries that account for about 80% of the world's population and a greater share of its GDP, energy use and CO2 emissions. Evaluations of these programmes have found that they are saving significant amounts of energy and CO2 emissions and are highly cost effective; however, there is still scope for improvement in all economies and some have more developed programmes than others. In general there has only been limited cooperation between these programmes and while the developers of programmes have often been aware of the existence of similar efforts in other peer economies they have seldom had the time to do an extensive investigation or comparison of the features of peer programmes to be able to compare them to their own and learn from them. In recent years, however, there has been more awareness of the value of looking at peer programmes. When China began to develop their current MEPS and labelling programme after the passage of the 1997 Energy Conservation Law the authorities would often look to and be informed by programmes elsewhere. In consequence and depending on then product their current requirements share many common elements with those in place in the EU, the USA and Japan. By contrast the programmes developed in the large OECD economies have tended to be more inward looking. Regulatory processes have usually been conducted without direct consideration of efforts elsewhere and thus in many cases relevant information gathered in other jurisdictions has not always found its way into the thinking informing their development. In recent years though, things have

---

[1] The end-uses investigated are: room air conditioners (non-ducted), central air conditioners (ducted), chillers, household refrigeration appliances, household clothes washers, household clothes dryers, household clothes dishwashers, water heating appliances, televisions, digital television decoders (set top boxes), external power supplies, lighting (GLS, CFLs, fluorescent lamp ballasts, directional lamps, linear fluorescent lamps, HID lamps, LEDs), space heating devices, fans & ventilation, electric motors, cooking appliances, transformers, and commercial refrigeration equipment.

begin to change. When the EU adopted the Ecodesign directive in 2005 [2] the Commission made an explicit request for all new regulatory processes to begin by considering what relevant regulations and efficiency metrics had been developed elsewhere. Japan has been actively promoting its Top Runner approach to equipment energy efficiency and in the process its policy makers have become better informed regarding parallel efforts in peer economies. In recent times the US DOE has also requested that its contractors gather information on international test procedures as a precursor to the development or revision of national test procedures and there is a willingness to consider what's in place elsewhere that was not previously a concern.

Major economies including China, the EU, India, Japan and the USA have recently established the International Partnership for Energy Efficiency Cooperation (IPEEC), which is a high-level forum to facilitate the exchange of information and cooperation on energy efficiency policy. The IEA's 4E Implementing Agreement brings together some of the major economies in a common cooperative framework addressing energy efficiency in electric equipment; the Clean Energy Ministerial has developed the Super Efficient Equipment and Appliance Deployment (SEAD) [3] initiative, which is opening the way to broad cooperation on equipment energy efficiency transformation; the EU and USA have established a cooperative forum (the US-EU High Level Regulatory Forum) where senior program managers exchange information on their standards and labelling programs; and numerous other bilateral efforts are accelerating the rapidity of knowledge transfer between the principal policy makers.

Given the high degree of international activity with respect to energy efficiency standards and labelling schemes it's appropriate to consider what lessons can be learned from a better understanding of current practices among the major economies. In particular there may be opportunities to fast track technology adoption, shortcut the development of test procedures and efficiency metrics and to foster, when appropriate, greater alignment, or harmonisation, of practices and requirements.

In principle the existing programs have much to learn from each other, notably because:

- The range of equipment covered by the various programmes differs considerably suggesting there is scope to broaden coverage

- The stringency of requirements varies appreciably, suggesting there is on-going scope for ambition to be increased

- Energy test procedures and energy efficiency metrics frequently vary among economies, thereby making comparison of the ambition of performance comparison difficult. In some cases, the test procedures are inadequate for public policy purposes and in others energy performance test procedures have not been developed. Where test procedures have been developed in an economy but not adopted elsewhere there is a potential for fast track adoption

- The manner in which requirements encourage system-level, as opposed to component level, efficiency improvement are markedly different i.e. there can be very important differences in the boundary conditions applied when defining the equipment considered

- The apparent effectiveness of product energy labelling varies significantly

- The degree to which complementary policies to stimulate energy savings in products operated within energy using systems are applied varies even more greatly and may have even larger savings potential.

- In principle cooperative market transformation efforts, as envisaged by SEAD, can foster much greater and more rapid market transformation

- Compliance with requirements is often poorly assessed and sometimes weakly enforced

Despite this at present it is a relatively complex matter to compare requirements across the globe because product definitions can differ, energy test procedures are not fully aligned, efficiency metrics diverge and policy terms of reference differ. Nonetheless, in many cases there is a sufficient degree of alignment in these factors that it is possible to make more informed comparisons. In some other cases full alignment renders direct comparison possible. Whenever they can be made such comparisons greatly assist the policy making process because they remove uncertainty about the feasibility of reaching certain efficiency levels and facilitate fast-tracking of policy development through a “follow-my-leader” effect. Furthermore, harmonised testing and efficiency definitions greatly facilitate industry in the design, production and diffusion of energy efficient equipment as they: enhance clarity over efficiency requirements in different jurisdictions, reduce testing and compliance costs and minimize the need for regionally distinct product platforms.

What is meant by harmonisation?

In principle greater international harmonisation can be imagined for all the different activities that underpin equipment energy efficiency programs; however, easily the largest potential to stimulate energy savings is via greater policy-level harmonisation (assuming this is to harmonise upwards). The key determinants of policy induced savings are the range, ambition and rigour of the energy efficiency policy portfolios. In the case of standards and labels these can directly apply to the packaged products or to components within the products; depending on how system boundaries are defined more or less of a system of energy using or influencing elements may be captured in these requirements and this can have a large baring on the eventual savings to be expected.

In theory policy harmonisation will only lead to energy savings if the parties concerned agree to harmonise at more ambitious policy levels than are the current norm. Conceptually very significant savings could accrue were there to be an upwards harmonisation that served to increase the coverage, scope and ambition of end-use energy efficiency policy settings above base-case levels. Furthermore, in principle the highest level is not a static requirement. Technologies improve and manufacturing costs decline as better manufacturing techniques are developed and economies of scale are achieved. Therefore if harmonisation were to be based on regular revision to new highest justifiable levels, it would save more energy again.

The prospects for harmonised energy test procedures

Energy performance test procedures underpin all equipment standards and labelling programs because they are the means by which equipment energy performance is measured and compared. Harmonisation of energy performance test procedures is not an end in its own right but is potentially a means of facilitating common energy policy, technology diffusion and trade objectives. In principle greater harmonisation facilitates trade, conformity assessment, comparison of performance levels, technology transfer and the accelerated adoption of best practice policy settings; however, it is important that this doesn’t come at the expense of the fitness for purpose of the test procedure in the local context. The ideal test procedure is: repeatable (gives the same result each time the product is tested in the same lab); reproducible (gives the same result each time the product is tested in different labs); gives an accurate measure of energy consumption reflective of in-situ consumption; gives an accurate measure of energy efficiency reflective of the in-situ energy efficiency ranking; and is not costly or overly time consuming. In practice, any test procedure is a compromise between these objectives. Therefore when considering the merits of harmonizing test procedures it is also important to consider whether a single international test procedure will be adequate for local usage and to consider the adequacy of the existing international test procedures for energy policy purposes.

The review of energy performance test procedures done for the harmonisation study [1] assessed each test procedure in use for the 24 equipment types in each of five economies against these criteria and assessed the degree to which they are already aligned, the nature of the differences that exist between them and the fitness for use of the international test procedures. The analysis then reviewed test procedure development dynamics and assessed the status of discussions at the international level to determine what the prospects were for greater harmonisation at the international level. For each product, a subjective assessment was made of the degree of international harmonisation based on analysis of the ongoing work on test procedures at regional and international levels. It was found that the degree of harmonisation for test procedures is relatively high for air conditioners and chillers, external power supplies, some of the lighting products (incandescent lamps (GLS), CFLs, and linear fluorescent lamps (LFLs)), electric motors and transformers. While for products like refrigerators, clothes washers and dryers, water heating appliances, and space heating appliances the degree of harmonisation of test procedures is relatively low. Not surprisingly, the greatest prospects for harmonisation occur when a new product is developed or when there are few existing national test procedures. This is the case for green-field products like LEDs, but can also be the case when test procedures or national efficiency requirements have not yet been set or have only been set in a single economy, such as for directional lamps. But it is also possible to harmonise test procedures for mature products. The recently revised IEC test procedure for asynchronous electric motors is an excellent example of this where the adoption of the best elements of other widely used international test procedures has enabled a broad international consensus to be established around the adoption of the new test procedure. This standard is now being written into energy performance legislation in Europe, North America and China.

Comparing policy settings in the major economies

The study this paper reports on [1] compares policy settings across the five major economies and determines the benefits that might accrue from wider alignment of policy settings and especially minimum energy performance regulations at the current highest international level. It gives examples regarding the savings that would accrue from upwards alignment of MEPRS in terms of scope and stringency, both of which are very significant. Just as important is the degree to which policy coverage could be extended by adopting requirements in place in one or more economies universally. This section now focuses on the difference in coverage of MEPRS and gives some specific examples from China, the EU and the USA.

Impact of Policy Coverage: The coverage of MEPS in the domestic sector

In many of the economies considered in the study the coverage of energy efficiency standards and labelling is already high or will be within a few years. China has the highest coverage of MEPs and labelling as a proportion of total energy use in the residential and commercial sectors, followed by the USA, the EU/Japan (both similar) and India. Figures 1 to 4 show the estimated electricity consumption of domestic equipment and the proportion of this that was subject to MEPS in 2010 for China, the EU, India and the USA. The difference in length between the top bar and the lowest bar in each of these figures shows the amount of electricity consumption that is not yet subject to MEPS. From this it is clear that India and the EU had the lowest proportion of domestic electricity consumption covered by MEPS and that China and the USA had the highest in 2010. The full report contains similar assessments for the other energy end-uses in the commercial and in industrial sectors and also addresses gas and oil-fired equipment.

How much might be saved? The Example of the European Union

The EU, which includes some of the first countries in the world to have set energy efficiency standards, ironically took rather a long time to adopt framework legislation to facilitate the rapid adoption of mandatory requirements. However, since the adoption of the Eco-design directive [2] in 2005, a proactive process has been underway to develop and adopt implementing regulations that require minimum performance levels to be satisfied by a range of different energy using equipment types. The projected impact of these measures can be seen in Table 1. From this it is apparent that in 2008 the MEPS in place in the EU only covered 4% of electricity use in all sectors and 72% of oil and gas use in the residential and commercial sectors. As of April 2010 the coverage had increased to 38% of electricity use in all sectors and about the same share of oil and gas use in the residential and commercial sectors. Ecodesign processes and measures which are currently pending finalisation or regulatory approval may increase this coverage to 75% of electricity use in all sectors, and about the same share of oil and gas use in the residential and commercial sectors. However, were the World's best MEPS to be adopted (defined as the most ambitious for each product currently in place) this would increase to 85% of electricity use in all sectors and 98% of oil and gas use in the residential and commercial sectors. Furthermore, adopting these MEPS would save about 200 TWh of additional energy use per year in 2030 compared to what is envisaged with the existing and pending regulations[2]. However, it is estimated that universal adoption of the world's best current technology (defined as the most energy efficient currently available) would save about 940 TWh annually. The disparity between these figures gives an indication of how much more demanding current MEPS could be even when considering the most ambitious.

Figures 5 to 7 show the same information, for the residential sector only, for the economies of China, the EU and the USA. From this it is clear that all of the economies would realise significant energy savings from matching their requirements with the world's best MEPS (i.e. the current most ambitious MEPS) but that far more could be saved by measures that would truly stimulate the adoption of the most energy efficient equipment currently available. The domestic equipment has the highest policy coverage at present and so the results reported in the full report for the commercial and industrial sectors show even greater savings can be achieved in those sectors.

[2] Note: assumptions have had to be made for the EU regarding the nature of Ecodesign implementing measures that are likely to adopted for on-going Ecodesign regulatory processes. The assumptions made here assume that relatively ambitious measures will be adopted thus the projected savings from adoption of World's Best MEPS could be higher than indicated here.

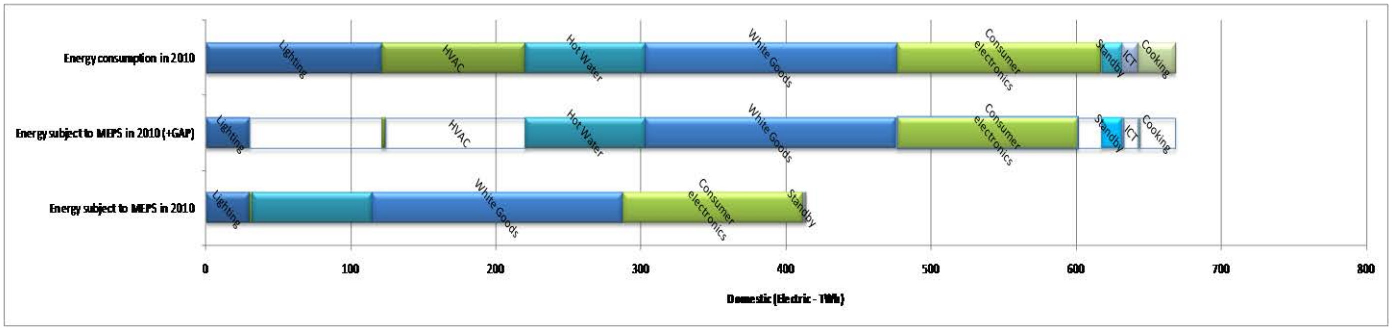


Figure 1. Domestic electricity consumption in 2010 and share of consumption currently subject to MEPS for China

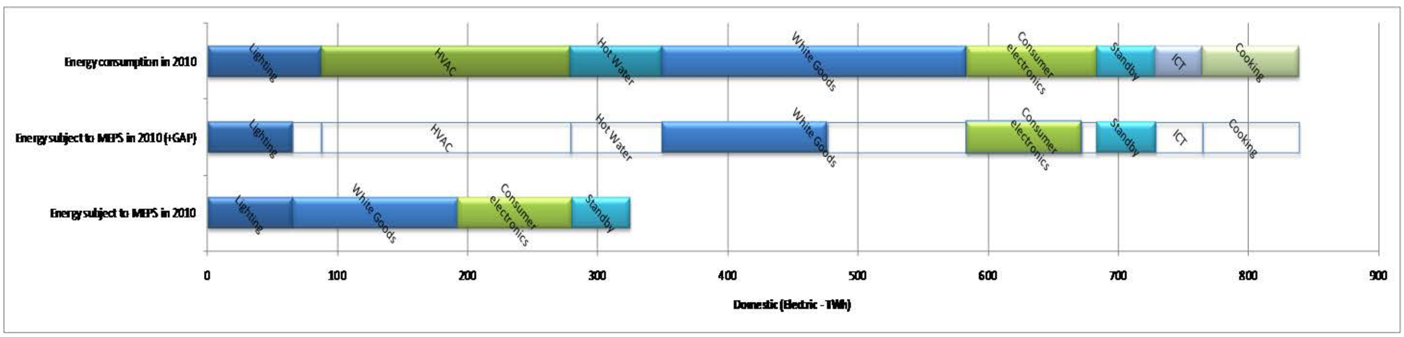


Figure 2. Domestic electricity consumption in 2010 and share of consumption currently subject to MEPS for the EU

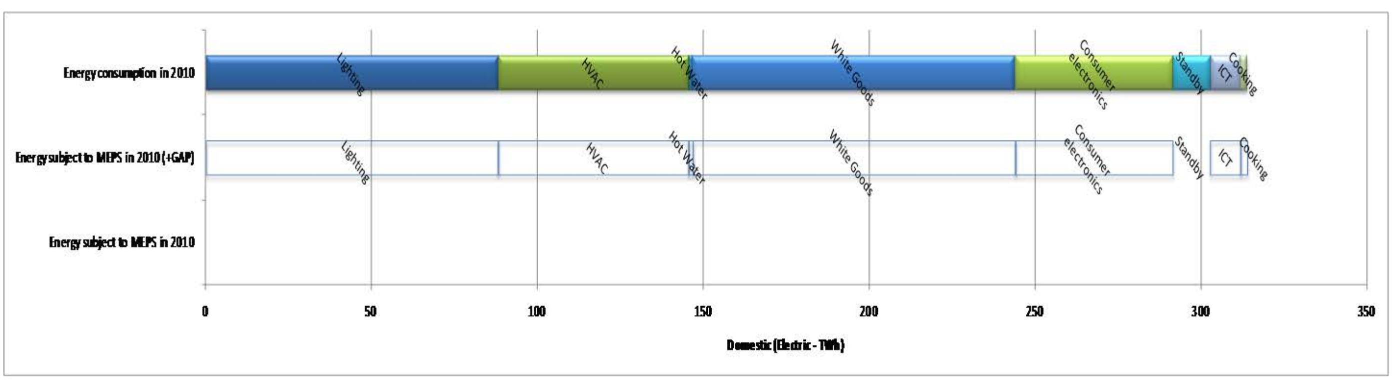


Figure 3. Domestic electricity consumption in 2010 and share of consumption currently subject to MEPS for India

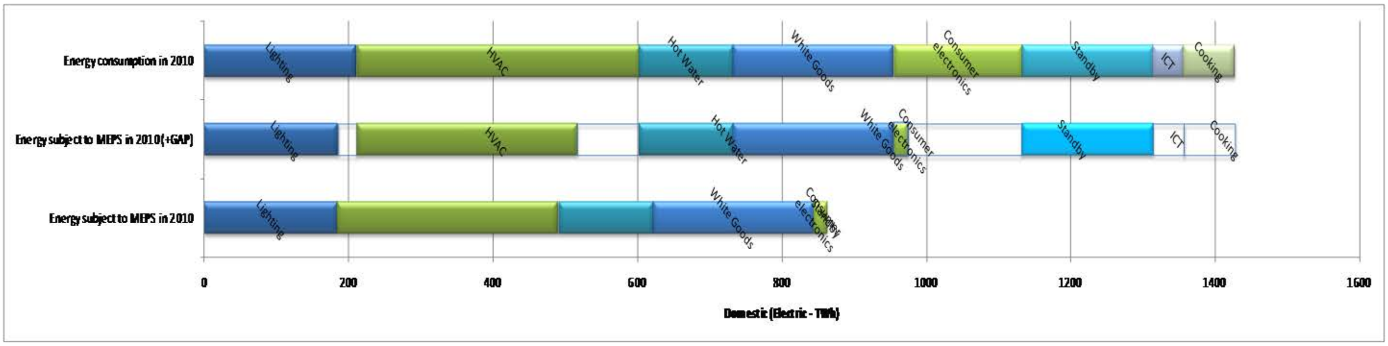


Figure 4. Domestic electricity consumption in 2010 and share of consumption currently subject to MEPS for the USA

Table 2. Energy Consumption, Share of Energy Subject to MEPS, and Potential Future Savings for the EU

	Domestic (electric) (TWh)									Domestic (oil+gas) (TWh)			
	Lighting	HVAC	Hot Water	White Goods	Consumer electronic	Standby	ICT	Cooking	**Total**	Heating	Hot Water	Cooking	**Total**
Energy consumption in 2010	87	192	71	233	100	45	37	74	839	1742	441	68	2251
Energy consumption in 2020	61	219	81	260	77	24	42	84	846	1817	451	74	2342
Energy consumption in 2030	70	249	92	293	98	15	47	96	961	1892	461	88	2441
Energy subject to MEPS in 2010	66	0	0	127	88	45	0	0	325	1742	441	0	2184
Energy subject to MEPS in 2020 (with pending)	51	219	81	260	77	24	42	74	826	1817	451	0	2268
Energy subject to MEPS in 2020 (with worlds best)	61	219	81	260	68	24	34	73	818	1817	451	0	2268
Energy subject to MEPS in 2030 (with worlds best)	70	249	92	293	88	15	39	83	929	1892	461	0	2353
MEPS coverage 2010	75%	0%	0%	54%	88%	100%	0%	0%	39%	100%	100%	0%	97%
MEPS coverage 2020 (with pending)	84%	100%	100%	100%	100%	100%	100%	88%	98%	100%	100%	0%	97%
MEPS coverage 2020 (with worlds best)	100%	100%	100%	100%	89%	100%	81%	87%	97%	100%	100%	0%	97%
MEPS coverage 2030 (with worlds best)	100%	100%	100%	100%	90%	100%	81%	87%	97%	100%	100%	0%	96%
Additional 2030 savings from Worlds Best MEPS	3	26	9	0	1	0	4	8	50	0	9	0	9
Additional 2030 savings from Worlds Best Technology	19	124	37	108	15	4	7	14	328	132	28	0	160
Additional 2030 savings from Worlds Best MEPS	4%	10%	10%	0%	1%	0%	9%	9%	5%	0%	2%	0%	0%
Additional 2030 savings from Worlds Best Technology	26%	50%	40%	37%	16%	25%	16%	14%	34%	7%	6%	0%	7%
	Commercial (electric) (TWh)									**Commercial (oil+gas) (TWh)**			
	Lighting	HVAC	Hot Water	Refrig-eration	Standby	ICT	Cooking	Pumps	**Total**	Heating	Hot Water	Cooking	**Total**
Energy consumption in 2010	168	223	109	68	10	84	42	47	751	626	181	24	831
Energy consumption in 2020	192	229	124	78	3	95	47	53	823	678	198	26	902
Energy consumption in 2030	219	267	142	89	6	109	54	61	946	730	216	31	977
Energy subject to MEPS in 2010	168	54	0	0	10	0	0	0	232	0	0	0	0
Energy subject to MEPS in 2020 (with pending)	192	126	0	78	3	67	47	53	568	0	0	0	0
Energy subject to MEPS in 2020 (with worlds best)	192	79	124	78	3	46	0	53	576	678	198	0	876
Energy subject to MEPS in 2030 (with worlds best)	219	90	142	89	6	52	0	61	658	730	216	0	946
MEPS coverage 2010	100%	24%	0%	0%	100%	0%	0%	0%	31%	0%	0%	0%	0%
MEPS coverage 2020 (with pending)	100%	55%	0%	100%	100%	70%	100%	100%	69%	0%	0%	0%	0%
MEPS coverage 2020 (with worlds best)	100%	34%	100%	100%	100%	48%	0%	100%	70%	100%	100%	0%	97%
MEPS coverage 2030 (with worlds best)	100%	34%	100%	100%	100%	48%	0%	100%	70%	100%	100%	0%	97%
Additional 2030 savings from Worlds Best MEPS	2	23	14	9	0	6	0	0	53	58	4	0	63
Additional 2030 savings from Worlds Best Technology	61	96	57	22	1	12	9	0	258	95	13	0	108
Additional 2030 savings from Worlds Best MEPS	1%	8%	10%	10%	0%	5%	0%	0%	6%	8%	2%		6%
Additional 2030 savings from Worlds Best Technology	28%	36%	40%	25%	25%	11%	16%	0%	27%	13%	6%		11%

Table 2 continued. Energy Consumption, Share of Energy Subject to MEPS, and Potential Future Savings for the EU

	Industry (electricity) (TWh)								All (TWh)		
	Motors >1kW	Motors >375kW	Pumps	Mechanical Motion	Fans	Compr-essors	Other	**Total**	Electricity	Oil+Gas	All
Energy consumption in 2010	609	203	166	301	127	198	372	1185	2775	3082	5856
Energy consumption in 2020	634	211	173	313	132	206	388	1233	2903	3244	6147
Energy consumption in 2030	660	220	180	326	137	214	404	1284	3190	3418	6609
Energy subject to MEPS in 2010	609	0	0	0	0	0	0	609	1167	2184	3350
Energy subject to MEPS in 2020 (with pending)	634	0	173	0	0	0	0	807	2201	2268	4470
Energy subject to MEPS in 2020 (with worlds best)	634	0	0	0	0	206	0	840	2235	3144	5379
Energy subject to MEPS in 2030 (with worlds best)	660	0	0	0	0	214	0	875	2462	3299	5761
MEPS coverage 2010	100%	0%	0%	0%	0%	0%	0%	51%	42%	71%	57%
MEPS coverage 2020 (with pending)	100%	0%	100%	0%	0%	0%	0%	65%	76%	70%	73%
MEPS coverage 2020 (with worlds best)	100%	0%	0%	0%	0%	100%	0%	68%	77%	97%	88%
MEPS coverage 2030 (with worlds best)	100%	0%	0%	0%	0%	100%	0%	68%	77%	97%	87%
Additional 2030 savings from Worlds Best MEPS	17	0	7	0	7	11	0	41	145	72	217
Additional 2030 savings from Worlds Best Technology	39	10	67	65	55	54	0	289	875	268	1142
Additional 2030 savings from Worlds Best MEPS	3%	0%	4%	0%	5%	5%	0%	3%	5%	2%	3%
Additional 2030 savings from Worlds Best Technology	6%	5%	37%	20%	40%	25%	0%	22%	27%	8%	17%

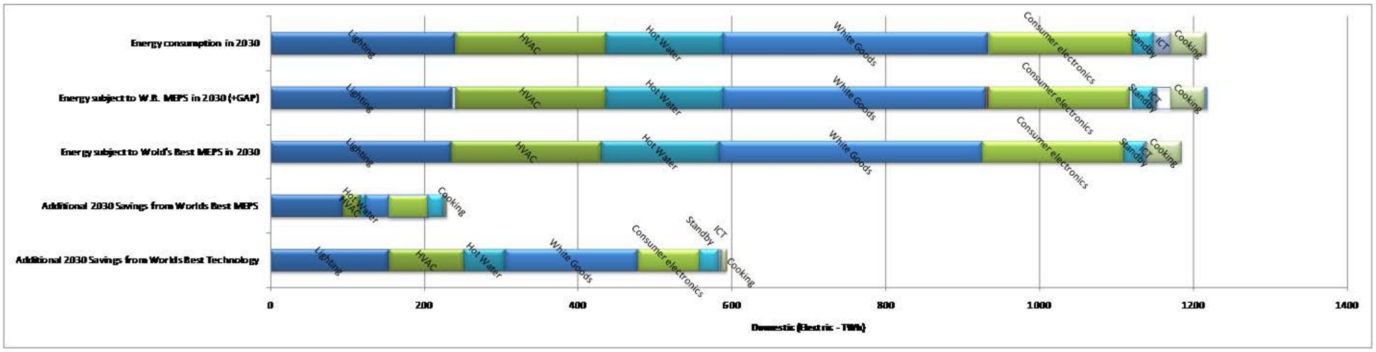


Figure 5. Domestic electricity consumption, share of energy subject to MEPS, and potential future savings for China

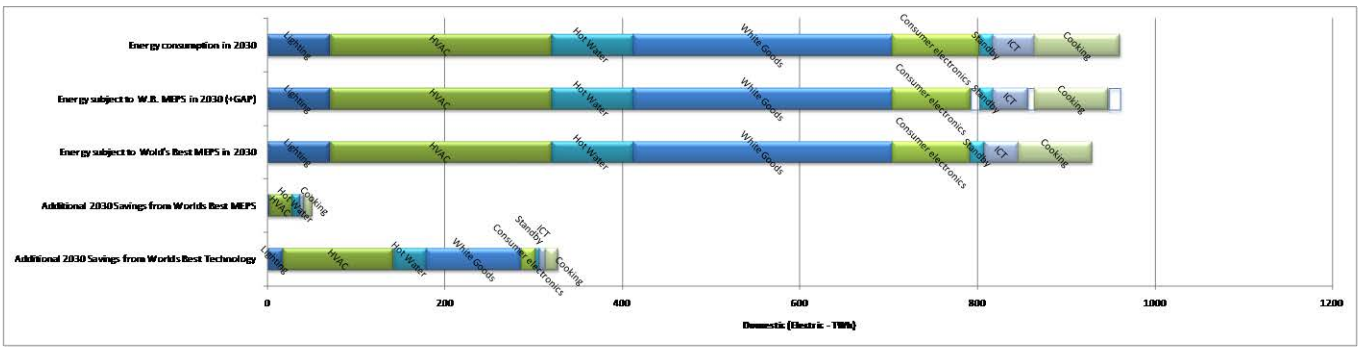


Figure 6. Domestic electricity consumption, share of energy subject to MEPS, and potential future savings for the EU

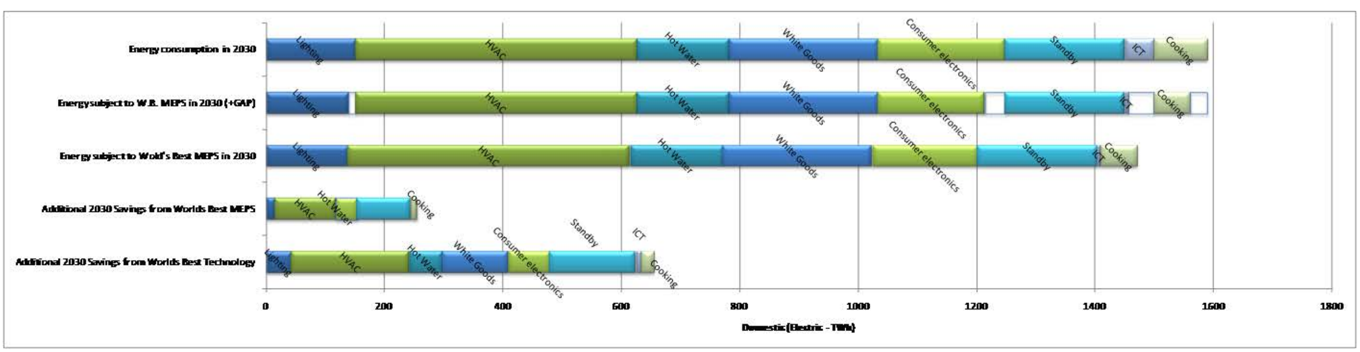


Figure 7. Domestic electricity consumption, share of energy subject to MEPS, and potential future savings for the USA

Estimating the potential for global savings from World's Best MEPS

The study also reports findings from a simplified analysis to consider what the savings might be at the global level from the adoption of World's Best MEPs. The analysis is based on extrapolating the detailed savings analyses for China, the EU, India and USA and the more approximate analyses for Japan and applying these to what the authors knew about the state of equipment energy efficiency performance and policy requirements in the rest of the world. From this it is found that were the current most broadly based and stringent equipment energy efficiency regulations to be adopted world-wide by 2030 it would save:

- 4000 TWh of final electricity demand (12% of the projected total) and 45Mtoe of oil and gas demand in the residential, commercial and industrial sectors excluding energy used for transport and industrial process heat
- 2600 Mt of CO2 emissions (11% of the projected total from the sectors addressed)

These savings arise because existing policy coverage is incomplete (ranging between 0% and about 70% of the energy use in the sectors considered) and because the stringency and manner in which permissible energy per unit service is determined leaves some large unexploited opportunities, even in the most advanced programs. Policy coverage is particularly incomplete for the commercial and industrial sectors while increased stringency in line with current world best practice would lead to substantial additional energy savings for the broad end uses of: lighting, HVAC, industrial electric motors, consumer electronics and white goods.

Conclusions

Traditionally the major OECD member economies of the EU, Japan and the USA have only paid limited regard to the test procedures and policy settings in place in the other major economies when setting their own requirements. This has led to today's pattern where product policy-settings are only weakly internationally aligned beyond the regional level. However, more recently there has been a trend toward greater consideration of other programmes during domestic deliberations on equipment energy efficiency policy and as this analysis has confirmed there are potentially great benefits from doing so.

There is clearly an opportunity to share information and to establish cooperative efforts to lower program costs and increase overall effectiveness and dynamism. There are numerous product/end-use specific harmonisation efforts that would benefit from greater support and would facilitate direct performance comparison and hence accelerated higher policy ambition. These include:

- targeted harmonised test procedure development (aiming to secure globally harmonised test requirements and efficiency metrics for all new or emerging products which don't yet have test procedures, e.g. for LEDs) and alignment efforts (supporting efforts to agree aligned revision of existing test procedures and efficiency metrics)
- instigating and supporting dialogues on best practice and opportunities with respect to harmonised conformity assessment
- pooling international data used in techno-economic assessments of savings potentials that underpin standards development and setting processes
- sharing information on best practice in standards setting tools and methodologies
- sharing information of policy settings, scope and ambition

Were there to be accelerated adoption of leading international energy efficiency policy requirements it would produce significant savings even within economies that currently have many of the highest energy efficiency policy settings. For economies that currently have only limited efficiency requirements the savings from accelerated adoption of world's best requirements would stimulate much larger savings.

References

[1] Waide, P., Harrington, H. & Scholand, M. (2010), *Study to Assess Opportunities for Success and CO2 Savings from Appliance Energy Efficiency Harmonisation*. Navigant Consulting Europe with Energy Efficiency Strategies on behalf of the Collaborative Labelling and Appliance Standards Program, Washington D.C.

[2] EUP (2005) Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005: establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council, Official Journal of the European Union L 191/29, 22.7.2005.

[3] Super Efficient Equipment and Appliance Deployment Initiative (SEAD), http://www.cleanenergyministerial.org/sead/index.html

Max Tech Appliance Design: Potential for Maximizing U.S. Energy Savings through Standards

Karina Garbesi, Louis-Benoit Desroches, Christopher Bolduc, Gabriel Burch, Griffin Hosseinzadeh, Seth Saltiel

Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

Abstract

This study surveyed the technical potential for efficiency improvements in 150 categories of appliances and equipment, representing 33 quads of primary energy use across the U.S. economy in 2010, and (1) documented efficient product designs, (2) identified the most promising cross-cutting strategies, and (3) ranked national energy savings potential by end-use. Savings were estimated using a method modeled after the U.S. Department of Energy (DOE) priority-setting reports—simplified versions of the full technical and economic analyses performed for rulemakings. This study demonstrates that large savings are possible by replacing products at the end of their life with ultra-efficient models that use existing technology. Replacing the 50 top energy-saving end-uses (constituting 30 quads of primary energy consumption in 2010) with today's best-on-market equivalents would save about 200 quads of U.S. primary energy over 30 years (25% of the anticipated consumption). For the 29 products for which maximum feasible savings potential could be estimated, the savings were twice as high. These results demonstrate that pushing ultra-efficient products to market could significantly escalate carbon emission reductions and is a viable strategy for sustaining large emissions reductions through standards. The results of this analysis were used by DOE for new coverage prioritization and to identify key opportunities for product prototyping and market development. The results will leverage future standards rulemakings by identifying the full scope of maximum feasible technology options. High-leverage products include advanced lighting systems, heating, ventilation, and air-conditioning systems, and televisions. High-leverage technologies include electronic lighting, heat pumps, variable speed motors, and a host of controls-related technologies.

Introduction

It is well established that energy efficiency is typically the least-cost approach to carbon emissions reductions and that major climate disruption cannot be avoided without aggressive and rapid efficiency improvements. Moreover, national investments in energy efficiency can be highly cost-effective. For example, the cumulative impacts of residential energy efficiency standards from 1987 – 2050 are expected to yield a benefit/cost ratio of 2.7:1 [1].

With an eye toward identifying promising candidates and strategies for energy efficiency regulation, the Max Tech and Beyond project sought to answer the following questions.

- How much energy could the United States save if the most efficient (Max Tech), currently feasible design options were adopted universally?
- What design features could produce those savings?
- How would the savings from various technologies compare?

To answer these questions, the Max Tech and Beyond project examined energy end-uses in the residential, commercial, and, in some cases, the industrial sectors, considering the energy savings potential and design characteristics of best-on-market products, best engineered products (that is hypothetical products that could be produced using best-on-market components and technology), and emerging technologies.

This paper presents the results of three analyses based on that work:

- an analysis of the cross-cutting strategies most promising for reducing appliance and equipment energy use;
- a product-level analysis of energy savings potential; and
- a macro-analysis of the U.S. energy-saving potential inherent in promising ultra-efficient appliance technologies.

Methods

Given the many thousands of candidate products, we used a multi-faceted, iterative research approach to limit the possibility of missing important end-uses, technologies, and design strategies, within time and cost constraints. The project began with a series of brainstorming sessions with the Energy Efficiency Standards team at Lawrence Berkeley National Laboratory (LBNL), which has more than a century of cumulative experience in appliance energy analysis,. At various times involving a dozen technical staff, the sessions were punctuated strategically by systematic data collection efforts for energy efficient technologies documented in academic, industry, and sources. We took both a top-down and bottom-up approach to identify potential both by end-use and by strategy.

- The top-down approach: Residential and commercial energy end-use consumption was broken down into as fine a resolution as possible and ranked to avoid missing potentially significant end-uses. Annually the U.S. DOE presents U.S. energy use forecasts in its Annual Energy Outlook (AEO) [2], based on results from the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) [3], which builds its estimates based on appliance-level energy use data. To obtain energy use estimates at the appliance level, we ran NEMS (the 2010 EIA release) using the AEO reference case assumptions and extracted the finest resolution data from the results.

- The bottom-up approach: Products were considered as composites of a relatively small number of common functions (heating, cooling, lighting, blowing, pumping, compressing, force-applying, computing, displaying, and so on). We then considered the best-available technologies to serve those functions and how such technologies might be combined into ultra-efficient products.

Although data on the energy efficiency of various products are abundant in product catalogs—and some sources, in particular the websites of ENERGY STAR® and the California Energy Commission [CEC], even compile that information—it is more difficult to determine what technologies and components are used to achieve those high efficiencies. Indeed, such information often is regarded as proprietary. One source has that information in relative abundance, but only for certain products covered by energy efficiency standards: the engineering analysis chapters of the Technical Support Documents (TSDs) of the U.S. Department of Energy's appliance standards rulemakings.[4] A meta-analysis of data contained in recent TSDs revealed a number of critical cross-cutting design strategies.

Data collection included:

- an exhaustive review of TSDs produced for DOE's energy efficiency standards rulemakings, as discussed above;
- an exhaustive review of energy efficient appliance databases on the CEC [5] and ENERGY STAR [6] websites;
- a systematic examination of recent technology reports from key sources such as TIAX [7], ASHRAE [8],and *Appliance Magazine*;
- keyword searches of other industry and academic journals;
- targeted Internet searches;
- participant observations at the American Council for an Energy Efficient Economy (ACEEE) Summer Study and ACEEE Behavior, Energy, and Climate Change Conferences; and
- consultations with industry and research experts on lighting, televisions, transformers, motors, pumps, compressors, and magnetic refrigeration.

In addition, we contracted detailed reports on key products from industry experts for the following technologies: consumer electronics, lighting (general, fluorescent, high intensity discharge), motors, air conditioning, industrial pumps, and compressors.

Results

Cross-cutting strategies with major energy savings potential

A handful of cross-cutting technologies and strategies that are applicable to many products and sectors have the potential to yield large energy savings. Table 1 shows the estimated energy savings of Max Tech technologies relative to standard appliance design practices and technologies, ranked in approximate order of product-level energy savings potential. While electronic lighting and heat pumps stand out as technologies with very large product-level energy savings, controls-related strategies stand out in terms of both extremely large energy savings potential in many cases and the remarkably broad applicability of the concept from the micro-chip level in computers to variable-speed control of large-scale industrial pumps.

Taking a closer look at two of these technologies indicates how large the potential energy and cost savings are.

- Using variable-speed drives (VSDs) in all appropriate motor applications today would save an estimated 9% of U.S. electricity (see Appendix A). Given that energy use can reach 90% of the life-cycle cost of a large industrial motor, the added cost of a VSD motor can pay back within a year.

- In recent years, highly efficient permanent magnet (PM) motors have been cost-negative compared to comparable-capacity induction motors, because their very small size saves significant quantities of copper and steel. The potential energy savings are largest for small motors (< 10 horsepower), in part because relatively stringent standards are in place for larger motors. For small motors, PM rotors save 7 – 15% in energy use compared to current shipments and about 5% more energy savings than would be achieved with the most efficient induction motors, given their practical limits . Admittedly, though, the relative prices of these motors could change rapidly, given the volatility of metals prices and the scarcity and geographic concentration of the rare earth (permanent magnet) materials. If PM materials become too constrained, variable reluctance motors are an alternative, having efficiencies that are intermediate between induction and PM motors.

- Applying lighting best practices (efficient lamps, fixtures, and controls) throughout the U.S. economy today would save about 9% of U.S. electricity, cutting lighting energy consumption in half and saving almost 100 quads of primary (power plant) energy in 30 years.

Table 1. Cross-Cutting Energy-Saving Design Options, Ranked by Approximate Energy-Saving Potential.

Approach	Products to which strategy is applicable	Comments	Energy-saving potential (approximate)
Max Tech (market-proven technologies)			
Electronic lighting (fluorescent and LED) replace conventional incandescent lighting	Mostly residential lighting	Only the residential sector remains dominantly incandescent. Although LED and CFL efficacies currently are similar, LED efficacies are expected to increase faster and have a higher technical potential to do so.	75% (commercial) 60% (residential)
Heat pump technology (HP, air and ground source) replace standard electric and gas heating	Water heaters, space heaters, and clothes dryers	Uses reverse-refrigeration cycle; efficiency can be enhanced by use of CO_2 as refrigerant; absorption cycle use for gas heat pump.	70% or more for CO_2-based electric HP 40-50% for gas absorption HP 25% – 50% dryers 30% – 40% space heating
Controls 1: Add power management	Lighting, consumer electronics; heating, ventilation, and air-conditioning (HVAC) systems; many appliances	Impact appears large, but involves large uncertainties; depends on the application and user behavior. Included are on/off controls, multi-level output, and output modulation. For electronic devices, includes more intelligent sleep modes and power scaling for chips.	50% – 70% (TVs) 20% – 50% (lighting) 5% – 30% (other electronics)
Controls 2: variable-speed drives (VSDs) replace single speed	Compressors, pumps, blowers, dishwashers, refrigerators, and air-conditioning systems	Advantageous only for applications that involve variable load conditions.	30% – 50%
Controls 3: multiple smaller components or devices to replace one larger one	Transformers, power supplies, compressors, and pumps	Applies to power conversion technologies and related systems that, at low loads, operate at low efficiencies. Turns off unneeded systems and operates the others at conditions closer to optimal efficiency.	20% – 50%
Efficient motors (many approaches: permanent magnet rotors, die-cast copper rotors, laminated amorphous metal cores, variable reluctance motors)	Any product that has a motor (from consumer electronics, to appliances, to large industrial machinery, and agricultural pumping equipment)	Different efficiency strategies may apply to different applications. In general the efficiency improvement potential is greater in smaller motors because current efficiency standards are already relatively high for large motors.	10% – 40%
Improved power supplies	Consumer electronics		2 – 5%
Beyond Max Tech (emerging technology)			
Organic LED	Electronic displays (portable electronics, TVs); lighting	Currently used primarily for small displays because of cost.	50 – 90%

Table 2 shows the potential energy savings for those applications for which detailed energy usage data were available—residential lighting, motors, and various heat pump applications. We could not analyze the commercial and industrial sectors in the same way. As Table 2 shows, although lighting clearly has significantly larger product-level energy-savings potential (with an even greater potential if controls are included), the combined savings from technologies that incorporate heat pump applications are comparable to the savings for lighting and motors.

Table 2. Estimated U.S. Residential Energy Savings if All Standard Technologies Had Been Max Tech In 2010.

Standard Technology	Replacement Technology	Energy Use[a] (TWh)	Savings Potential[b] (%)	Energy Savings (TWh/yr)
Lighting (incandescent, including reflector lamps)	Fluorescent or LED	212	60	127
Electric water heaters	Heat pump	130	50	65
Electric space heaters other than heat pumps	Heat pump	53	35	19
Electric clothes dryers[c]	Heat pump	43	38	16
Motors (all applications)[d]	VSD	527	40	158

[a] U.S. residential energy use by each standard technology in 2010. Values were estimated using the Energy Information Administration's (EIA's) National Energy Modeling System software (NEMS: http://www.eia.doe.gov/oiaf/aeo/overview/). In its *Annual Energy Outlook* (AEO) (http://www.eia.doe.gov/oiaf/aeo), EIA presents U.S. energy forecasts annually based on NEMS. Forecasts are needed to estimate current year energy use because actual data are not yet available. Although NEMS builds its estimates based on appliance-level energy use data, only broader end-uses are released. To obtain energy use estimates at the appliance level for the residential sector, we ran NEMS (the 2010 release) based on the AEO reference case.
[b] Based on the midrange of savings assumptions given in Table 1.
[c] Heat pump dryers are now on the market in Europe. In fact, Switzerland's recent energy efficiency standard for dryers effectively banned all but heat-pump dryers. See for example [11].
[d] Based on the following assumptions: motors account for 38% of residential electricity use (see Appendix A, Table 4); 75% of these motors would benefit from VSD; and penetration of VSDs in appliances currently is negligible.

Product-level analysis of energy savings potential

Energy savings potential was estimated for more than 150 products. In many cases, for example in the ENERGY STAR databases, energy use or efficiency is reported with no description of the technology responsible for the savings. Figure 1 documents the product-level energy savings potential (best-on-market with respect to shipment-weighted average) for the top 20 performers. It should be noted that small differences in energy savings potential should not be considered significant, because it was not possible to impose an absolutely consistent measure of comparison given the nature of the available data.

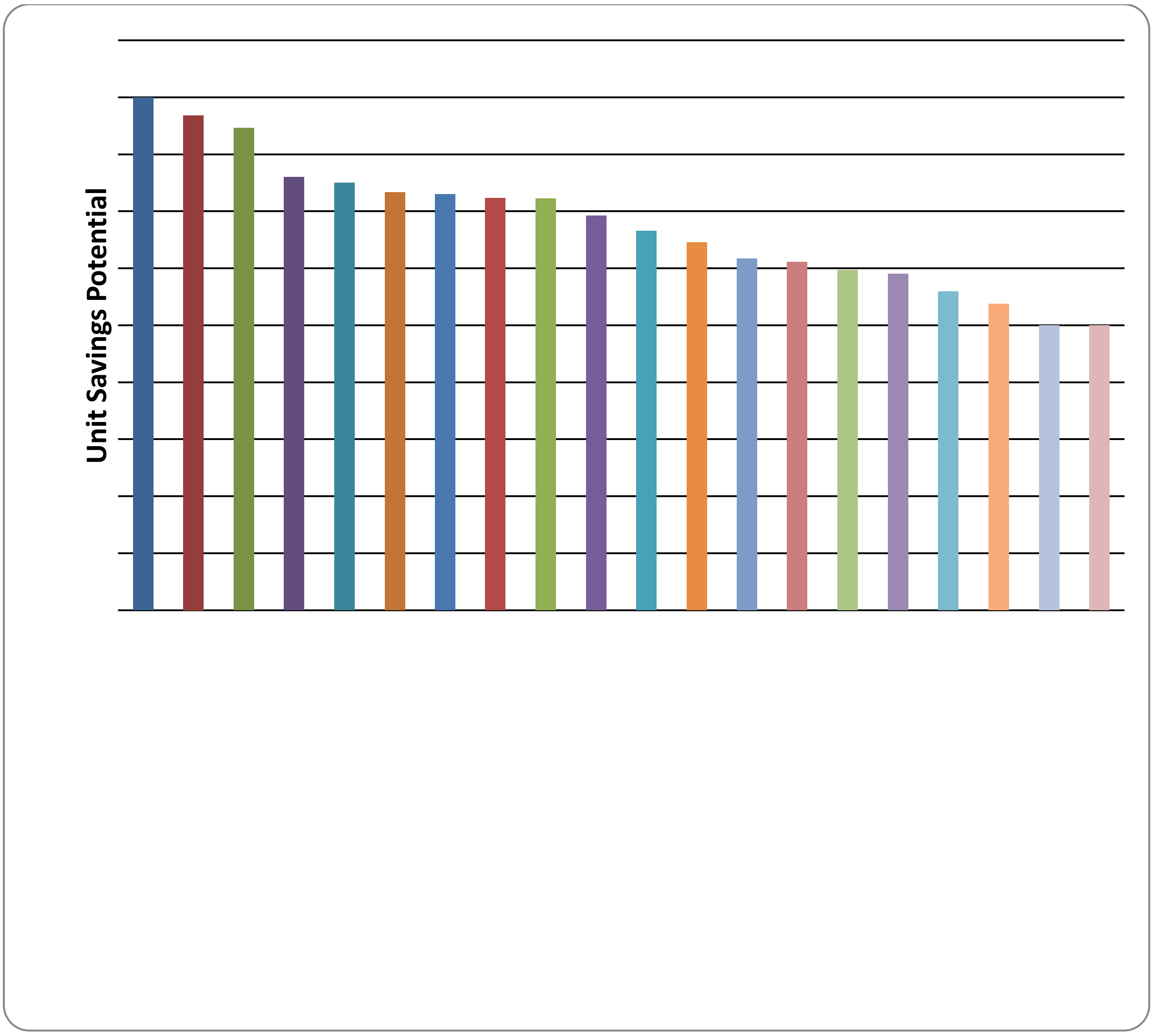


Figure 1.Top 20 End-Uses Ranked by Per Unit Savings Potential. (Savings based on best-on-market efficiency versus average efficiency of current shipments.)

Macro-Analysis of the U.S. Energy-Saving Potential of Ultra-Efficient Products

Technical Savings Potentials

We calculated the technical energy savings that would be obtained over 30 years, if the products sold today immediately started being replaced with the best-on-market products or with Max Tech (maximum technically feasible products) as old products failed. The method was modeled after DOE priority-setting reports, which serve as simple versions of the full technical and economic analyses performed throughout a DOE energy conservation standards rulemaking.[11] The 30-year savings estimates incorporate all existing standards and those scheduled to come into effect (to avoid double counting). They do not account for any other mechanisms that might affect product energy use (*e.g.* building energy codes). While a standards-based model is being used here, because of the large numbers of products considered, we are making no claims as to whether or not a particular product is amenable to energy efficiency regulation. This is solely an estimate of the technical potential for energy savings.

The calculations associated with *Max Tech and Beyond*, priority-setting, and standards rulemakings all assume a 30-year analysis period and a natural replacement cycle of older units in the installed base. In this project (unlike in the standards rulemaking process), the calculation does not account for a potentially growing installed base, because complete annual shipment data were not available for all products.

The calculations distinguish between site energy use (the electricity use at the home) and source energy use (the input fuel needed to produce that electricity). Reports related to DOE priority-setting and standards rulemakings give all energy values as source (or primary) energy. In this report, site electricity, natural gas, oil/gasoline, and water consumption are all considered separately for each product and combined into total primary energy consumption per product. Site energy use was converted to source energy use using the average national *heat rate* for 2025 (the midpoint of the period considered) from the Energy Information Administration's (EIA's) forecast in its *Annual Energy Outlook* for 2009 (adjusted for the economic stimulus bill). *Heat rate* is the multiplier used to convert all site electricity consumption into primary source energy consumption; DOE anticipates this conversion rate to be 10,650 British thermal units (Btu) source energy per kilowatt-hour (kWh) site energy. For natural gas, we assumed a 10% loss from source to site. We assumed that oil experienced no loss (*i.e.*, site energy equals source energy). In the case of water, energy is used for supply, transport, and pre- and post-treatment. The embedded site energy for water was assumed to be 3.4 terawatt-hours per trillion gallons.

We considered three energy use cases: (1) the base case; (2) a most efficient (best-on-market) case; and (3) and the maximum currently feasible (Max Tech) case, where possible. These cases are described below.

Base Case

To align with DOE priority-setting studies, the total stock (number of products) is assumed to remain constant for 30 years. The stock is replaced with units typical (in terms of efficiency) of new shipments at a constant rate throughout a single lifetime representative of the product. By the end of that lifetime, all the old stock has been replaced with units typical of new shipments. No further changes in the stock occur until the end of the 30-year period. In cases where a new standard is about to come into effect, we incorporated the standard's stipulated efficiency level into the estimates of new shipment efficiencies to prevent double-counting the energy savings from new technologies that will already be achieved through Federal minimum standards.

Best-on-Market Case

In this case we again assume that the total stock remains constant for 30 years. The stock is replaced with units representing current best-on-market product, at a constant rate throughout a single lifetime representative of the product. By the end of that lifetime, all of the old stock has been replaced with today's best-on-market equivalents. No further changes in the stock occur until the end of the 30-year period.

Max Tech Case

We again assume that the total stock remains constant for 30 years. The stock is replaced with Max Tech units that could be manufactured today (or in the very near future), at a constant rate throughout a single lifetime representative of the product. By the end of that lifetime, all of the old stock has been replaced with Max Tech units. No further changes in the stock occur until the end of the 30-year period.

Table 3 summarizes energy use and savings potentials for the best-on-market and Max Tech technologies for the top 50 products, in terms of U.S. energy savings potential over the next 30 years. The results for the top 20 products are also presented in graphical form in Figure 2. Table 3 is sorted by cumulative, 30-year savings potential in the best-on-market case, as not all products have Max Tech data. In addition to the 30-year potentials, the table shows primary energy reduction potentials (in percent per device). Note that Max Tech savings potentials are often much higher than best-on-market potential. In total, among the 150 products studied, we were able to estimate Max Tech potential for 29 products. For those 29 products Max Tech savings exceeded best-on-market savings by a factor of 2 on average (weighted by current end-use energy consumption).

Table 3. Top 50 End-Uses Sorted by Potential Cumulative 30-Year Energy Savings.

Product	Annual Primary Energy Use 2010 (quads)	Annual Reduction in Primary Energy Use for Best-on-market Product (%)	Annual Reduction in Primary Energy Use for Max Tech Product (%)	Cumulative 30-year Baseline Primary Energy Use (quads)	Cumulative 30-year Best-on-market Primary Energy Savings Potential (quads)	Cumulative 30-year Max Tech Primary Energy Savings Potential (quads)
Residential Lighting (general)	2.26	65%	79%	52.3	26.5	32.5
Commercial Lighting (general)	3.50	31%	57%	103.6	23.7	43.9
Res. Elec. Water Heaters	1.33	54%	62%	38.3	15.9	18.3
Central AC	1.92	39%		51.7	13.4	
General Pumps	1.53	25%	50%	46.0	10.2	20.3
Gas Furnaces	3.22	14%		94.9	8.5	
Televisions	0.87	50%	85%	18.8	7.2	12.3
Industrial Lighting	0.67	35%		20.1	6.1	
Central HP	1.16	25%		31.2	5.7	
Washer Extractors	0.28	85%		8.3	5.2	
Exterior Lights (*e.g.*, parking)	0.39	50%	60%	11.6	5.1	6.1
Air Compressors	0.96	20%		28.8	5.1	
Comm. Storage Water Heaters (gas)	0.42	50%		12.7	5.1	
Street Lights	0.35	49%		10.5	4.6	
Low-End Servers	0.29	56%	95%	8.7	4.6	7.8
Res. Gas Water Heaters	1.42	13%	51%	38.1	3.7	14.6
Comm. Storage Water Heaters (elec.)	0.27	50%		8.2	3.2	
Torchieres	0.22	69%	77%	5.0	3.1	3.5
Fume Hoods	0.28	50%		8.4	2.8	
Metal Halide Fixtures	0.75	21%		20.2	2.7	
Desktop Computers	0.54	24%	69%	12.5	2.7	7.9
Ceiling Fans	0.47	47%	78%	8.5	2.6	4.3
Desktop Monitors	0.15	59%		4.0	2.2	
Dishwashers	0.24	37%	46%	6.7	2.0	2.4
Clothes Washers	0.48	21%	83%	12.7	1.9	7.7
Clothes Dryers (elec.)	0.46	16%	44%	13.8	1.6	4.4
Non-General-Purpose Motors	0.19	30%		5.8	1.5	
Chillers - Centrifugal	0.21	26%		6.3	1.1	
Chillers - Air-Cooled Recip. & Screw	0.19	29%		5.6	1.1	
Compact (Shelf) Audio Systems	0.07	62%		2.0	1.1	
Liquid-Immersed Transformers	0.42	21%	61%	11.6	1.0	3.1
Comm. Steamers (elec.)	0.05	73%		1.6	1.0	
Small CUAC	0.39	12%		10.8	1.0	
Refrigerators	0.87	7%	20%	21.3	0.9	2.8
Comm. Ranges (gas)	0.09	41%		2.7	0.9	
Dry-Type Transformers	0.47	26%	48%	10.9	0.9	1.6
DVD/Blu-ray Players	0.05	72%		1.4	0.9	
Comm. Ovens (gas)	0.10	35%		2.9	0.9	
Large CUAC	0.35	12%		9.4	0.8	
Video Game Consoles	0.04	72%		1.1	0.7	
Boilers (gas)	0.43	10%		12.4	0.7	
Digital Satellite STB	0.07	38%		2.2	0.7	

Product	Annual Primary Energy Use 2010 (quads)	Annual Reduction in Primary Energy Use for Best-on-market Product (%)	Annual Reduction in Primary Energy Use for Max Tech Product (%)	Cumulative 30-year Baseline Primary Energy Use (quads)	Cumulative 30-year Best-on-market Primary Energy Savings Potential (quads)	Cumulative 30-year Max Tech Primary Energy Savings Potential (quads)
Very Small CUAC	0.22	15%		6.3	0.7	
Large Multifunction Devices	0.08	30%		2.4	0.7	
UPS (double conversion)	0.05	50%		1.4	0.6	
Medium Electric Motors	0.54	6%	25%	13.9	0.6	2.3
Cordless Telephones	0.10	22%		2.9	0.6	
Laser Printers	0.03	60%		1.0	0.6	
Air Cleaners/Humidifiers	0.06	33%		1.9	0.6	
Very Large CUAC	0.20	13%	79%	5.7	0.6	
TOTALS(*)	**30**			**820**	**200**	**200**

- Values rounded to two significant digits.

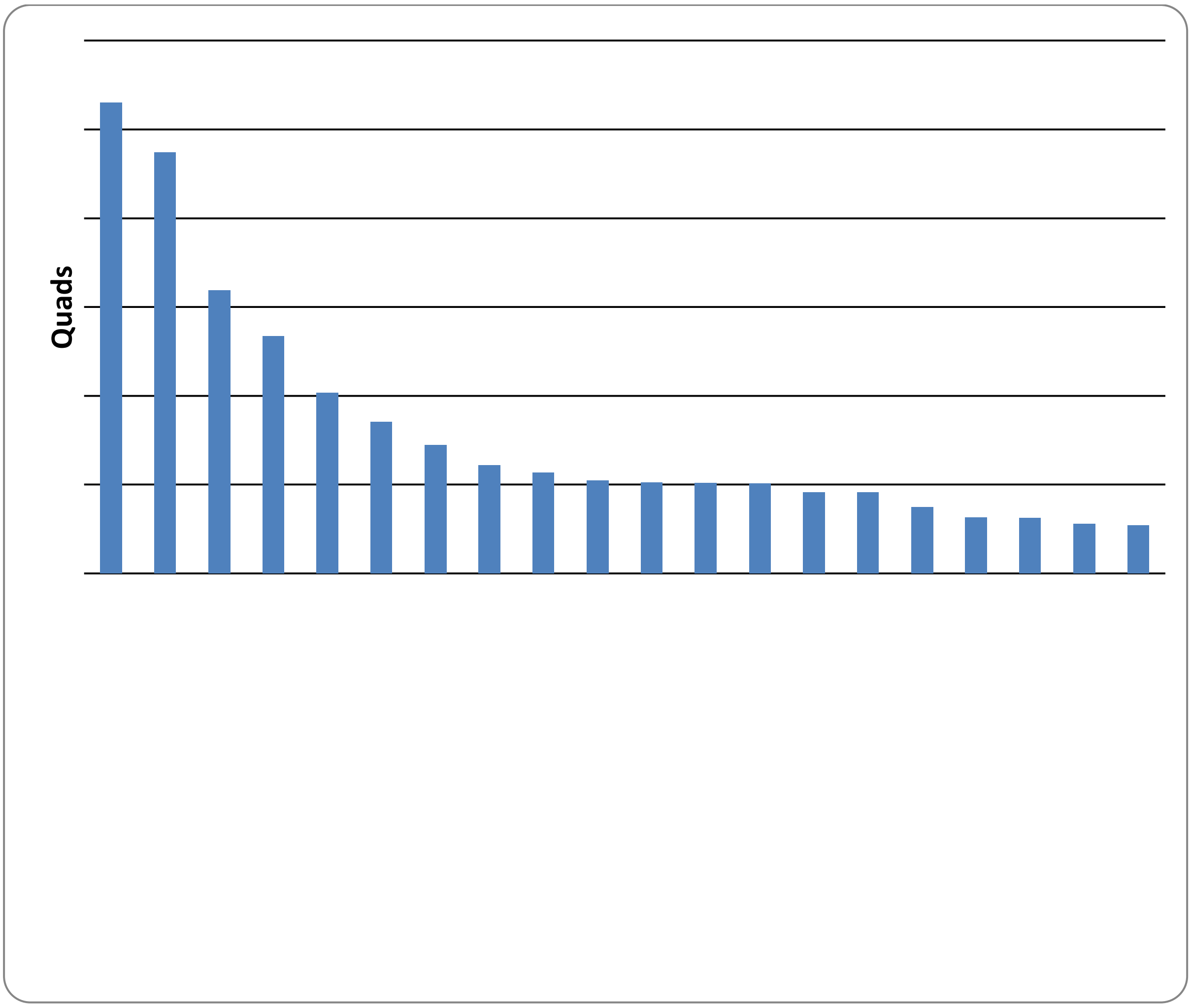


Figure 2. Cummulative 30-Year Energy Savings Potential of the Top 20 Products Ranked by Technical Potential for Energy Savings in the U.S. Economy. (Assumes that existing stock is replaced with current best-on-market product at the end of its lifetime.)

Conclusions

This study demonstrates that large energy savings are possible by replacing the stock of U.S. appliances and equipment at the end of their product lifetime with high efficiency products that use existing technology. Replacing the 50 top energy-saving end-uses (which currently constitute 30 quads of annual primary energy consumption) with products having energy efficiencies equivalent to today’s best-on-market products, would save the United States an estimated 200 quads of primary energy over the next 30 years—constituting 25% of the anticipated baseline consumption. For the 29 end-uses for which we were able to obtain credible data to estimate maximum feasible savings potential, the savings were twice as high (50%). Those products alone have the potential to save 200 quads over 30 years, suggesting a strategic advantage, from a policy standpoint, of pushing those technology advances to market. Combining the potential of the 29 max-tech products and the 21 remaining best-on-market products yields a total documented savings potential of 300 quads, which ignores the additional potential of MaxTech advances in the latter.

This study also demonstrates that there are clear winners in terms of energy-saving end-uses and cross-cutting technologies and strategies. With an estimated total technical potential for energy savings over 30 years of almost 100 quads (all lighting, all sectors), lighting emerged as the clear winner in terms of Max Tech end-use savings potential. Televisions (and other consumer electronics) also have a large and growing potential, with controls dominating that potential. Cross-cutting technologies of particular importance include heat pumps, variable speed motors, permanent magnet motors, and, as is already evident, controls strategies in general. The savings from energy management and controls can be very large, because better controls can improve the energy efficiency of products as diverse as computer micro-chips, lighting, consumer electronics, and large industrial motors.

These results demonstrate that pushing ultra-low-energy-use products to market could significantly escalate carbon emission reductions and is a viable strategy for sustaining progress toward significant emissions reductions through standards. That is, continuing to drive up efficiencies at the high end of the market, using eco-labeling, certification programs, and other mechanisms, enables the removal of low-performing products at the bottom of the market. That progress will not continue without appropriate incentives in place, one of which is the continued promise of increasingly stringent standards.

Studies like the one reported here are essential to prioritize the activities of standards programs, maximize the resulting emissions reductions and economic benefits, and to sustain emissions reductions progress over the long term. The results also highlight the need for new appliance and equipment test procedures that can capture the energy and carbon benefits of emerging advanced technologies, like solar-assisted appliances, DC-based power systems, hybrid designs, and system-based approaches. Given the constraints of the project, this study only begins to quantify the potential savings from systems level approaches and hybrid appliance designs, which could greatly leverage the large savings demonstrated herein.

References

[1] Meyers S., McMahon J.E., McNEil M. and Liu X. *Impacts of US federal energy efficiency standards for residential appliances.* Energy 28: 2003, pp. 755–767.

[2] U.S. Energy Information Administration, *Annual Energy Outlook*. Can be downloaded at: http://www.eia.doe.gov/oiaf/aeo.

[3] U.S. Energy Information Administration, *National Energy Modeling System*: An Overview. Available online at: NEMS: http://www.eia.doe.gov/oiaf/aeo/overview/.

[4] U.S. Department of Energy, *Appliances and Commercial Equipment Standards*. Rulemakings documented online http://www1.eere.energy.gov/buildings/appliance_standards/

[5] California Energy Commission, *Appliance Efficiency Database.* Available online at: http://www.appliances.energy.ca.gov/QuickSearch.aspx

[6] U.S. Environmental Protection Agency, *ENERGY STAR.* Products databases available online at: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products

[7] TIAX, *Publications and Reports*. Available online at http://www.ashrae.org/publications/page/540

[8] Ashrae Journal, Available online at http://www.ashrae.org/publications/page/540

[9] Appliance Magazine. Available online at http://www.appliancemagazine.com/contents/index.php

[10] Rogemma P. "Sustainability in Europe." *Appliance Magazine*. June 2007: http://www.appliancemagazine.com/editorial.php?article=1769&zone=1&first=1

[11] DOE. (2005). *Appendix A: FY2005 Technical Support Document*. Prepared in support of DOE's 2005 Priority Setting, updating the FY2003 priority setting. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/fy05_priority_setting_app_a.pdf

Implementing Measures of the Ecodesign Directive – Potentials and Limitations

Rikke Dorothea Andersen and Arne Remmen

Aalborg University, Department of Development and Planning

Abstract

The EU Directive on Energy-related Products (2009/125/EC) sets the frame for implementing ecodesign requirements for energy-using and energy-related products. The aim is to contribute to sustainable development by increasing energy efficiency and the level of environmental protection, while at the same time increasing the security of energy supply. The ecodesign requirements of the Directive are put forward in Implementing Measures (IM) based on comprehensive preparatory studies.

This paper focuses on the experience with the IM so far. In January 2011, eleven IM have been adopted. These IM focus on energy efficiency, power consumption, water consumption, information requirements and in some cases quality and performance issues. All IM only take the use phase of the products life time into consideration.

The ambition level of the IM is analysed through a detailed case study of the IM for televisions. It is argued that the IM have not succeeded in setting up sufficient ecodesign requirements, as only one life cycle phase and mainly one environmental impact category is addressed. The result of an analysis of televisions (TVs) on the market shows that new technologies have been developed that reduce power consumption significantly, and these technologies have been assessed not being mature enough to be included in the IM and the preparatory studies. Hence, it is concluded in this article that the process around the Ecodesign Directive has been too slow to be considered a driver for increasing material and energy efficiency of televisions. Furthermore, it can be concluded that technology development has been a more important driver during the past five years.

1. Introduction

In 2005 the EuP Directive (2005/32/EC) was adopted as part of the European Unions Integrated Product Policy (IPP). The directive establishes a framework for setting ecodesign requirements for energy using products. In 2009 the directive was recast, and the new directive (2009/125/EC) also includes energy related products in its scope. Throughout the paper "Ecodesign Directive" will be used to cover both the initial directive and the recast version.

The requirements of the Ecodesign Directive are set up in implementing measures (IM). The objective of the Directive is to ensure free movement on the market of products in compliance with the ecodesign requirements and "*it contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply*" [1]. The requirements of the IM will be gradually tightened in order to ensure continuous improvement.

In this paper, focus is on the experiences with the IM in the Ecodesign Directive so far. It is in particular analysed how the requirements in the IM fit with the theoretical understanding of ecodesign and the IM for televisions (TV) are analysed more in depth. First, a definition of ecodesign is necessary.

1.1 Definition of Ecodesign

Basically, ecodesign means environmentally conscious product development. Other similar concepts are Design for the Environment and Design for Sustainability [2, 3, 4, 5, 6, 7, 8]. In practice it implies that environmental considerations are integrated with the other considerations when developing products including functional, economic, safety and quality issues. Ecodesign focuses on all possible areas of improvements in the product's entire life cycle, from the definition of the function, over selection of raw materials, production methods and transport means, to how the use, recycling and disposal are organised. All relevant environmental properties should be addressed, including material and energy efficiency, emissions and hazardous substances. The aim of ecodesign is to fulfil a need with the least environmental impact, meaning that the function of the product should be the point of departure for future product development [2].

Figure 1 illustrates an ecodesign strategy wheel, developed by Han Brezet and Carolien van Hemel in 1997. The strategy wheel illustrates the steps and strategies that can be followed in ecodesign. The centre of the figure is a spider web illustrating the environmental profile of the product. In this case the blue area illustrates the environmental profile of the old product and the green area illustrates the profile of the new and ecodesigned product.

In the following the adopted IM of the Ecodesign Directive are analysed. In this analysis, we focus on all the life cycle phases and environmental impacts included in the IM. Hereafter, an in depth case study of the IM for televisions (TV) is presented. The focus areas of the IM are compared to the criteria of four ecolabels; the European Ecolabel, the Nordic Ecolabel, Energy Star and TCO'06 for Media Displays. The aim is to investigate which other environmental areas are assessed important by other instruments. The rationale is twofold; first of all, ecolabels are acknowledged by authorities, consumers and producers. Secondly, many years of experience and work are behind the ecolabels. The products fulfilling the criteria of eco-labels are considered among the best environmentally performing product in their category without compromising the quality. All ecolabels except the Energy Star consider the entire life cycle of the product. Consequently, they are in line with the definition of ecodesign. Finally, the performance of TVs on market are investigated and compared to the requirements in the IM.

2. Methods

The study is based on a literature review of the Ecodesign Directive, the IM for TV and four ecolabels; The European Ecolabel, The Nordic Ecolabel, Energy Star and TCO'06 [9, 10, 11, 12]. Information concerning the performance of TVs on the market has been gathered on the webpages of the producers. The TVs analysed are considered being the best available technology. TVs from the following brands were analysed:

- Samsung [13, 14, 15]
- Sony [16, 17]
- Philips [18]

3. Implementation of the Ecodesign Directive

The status in January 2011 is that eleven IM have been adopted. The first entered into force in January 2009. In Table 1 the focus areas of the eleven IM are listed. It is visible that all IM include either power consumption or energy efficiency in the requirements. The only exception is the IM for electric motors. This IM has a focus on motor efficiency which is also energy related. Five of the eleven IM focus solely on power consumption and/or energy efficiency, which is a high percentage of the IM. Other areas addressed by some of the IM are related to quality and performance issues. The only IM that stands out to some degree is the IM for washing machines, which has included requirements on water consumption in the IM. It is also noteworthy that all requirements are concerned about the use phase only.

Three conclusions can be drawn from this analysis:

1. Not all environmental areas are addressed in the IM, which is in contradiction with the concept of ecodesign as defined above, as all environmental areas should be addressed according to ecodesign.

2. Only one life cycle phase is addressed, which also is in contradiction with the concept of ecodesign, as all life cycle phases should be addressed according to ecodesign.

3. The requirements are in line with the concept of ecodesign when it comes to continuous improvement. As noted above the requirements are gradually tightened to achieve innovation.

According to Article 15, 4. (a) of the Directive the Commission shall, when preparing a draft for IM, "*consider the life cycle of the product and all its significant environmental aspects, inter alia, energy efficiency.*" It is in this article assessed that the narrow focus of the IM for TVs is a result of a too narrow interpretation of article 15, 4. (a) and hence only the most important environmental aspect is included in the IM. It can therefore be concluded that the Ecodesign Directive has the potential to regulate more environmental impacts of the products if not only the most important areas are addressed. In the following, four ecolabels are analysed with the aim of analysing which other environmental areas are assessed relevant to regulate by other instruments.

4. Implementing Measures for Televisions compared to Ecolabels

In this section the IM for TVs is analysed more in depth. According to the Danish Energy Agency the number of TVs in Danish households has grown rapidly in recent years from around 2.2 million in 1980 to 5.5 million in 2008 [31]. That equals a growth from approximately 1 TV per household in 1980 to around one per person in 2008. This rapid growth underlines the importance of investigating the environmental impact of TVs and set up requirements for TVs.

The focus areas of the IM for TVs and the ecolabels for TVs are compared in Table 2. The narrow focus of the IM for TVs is very clear in this comparison. All ecolabels except the Energy Star focus on general ecodesign criteria, dismantling, lifetime extension and chemicals, thereby setting criteria to several phases of the products' life cycle and to more environmental areas.

Taking a closer look at the energy criteria on on-mode power consumption, it is evident that the requirements of the IM are not as strict as the ecolabels, see Figure 2. The IM requirements for full HD are for example 1.7 times larger than the European Ecolabel criteria for 2009. The IM requirements for 2012 are more than 1.5 times larger than the European Ecolabel criteria for 2011. This is not surprising as they are different types of policy instruments. Ecolabels are meant as an incentive for frontrunner companies, whereas the IM are minimum requirements aiming at excluding the worst performing products from the market. However, the range between the two requirements, especially with the larger screen sizes, is quite big.

Furthermore, the IM requirements do not set an upper limit for maximum on-mode power consumption, thereby accepting the connection between screen size and power consumption. This is problematic since there is a trend towards bigger and bigger screens, with most likely higher power consumption. Both the Nordic and the European ecolabels have considered this and set a maximum on-mode power consumption of 200 Watt regardless of screen size.

5. Performance of Televisions on the Market compared to the Implementing Measures

In this section, the on-mode power consumption of televisions on the market is analysed and compared to the requirements of the IM. The aim is to assess the ambition level of the IM. The study was done in the winter of 2009/10 and again in winter/spring 2011. As the requirements entered into force in summer 2010, the study is performed half a year before and after the requirements entered into force.

TVs with ecolabels were first analysed in the study in 2009/10. These were regarded as the best available technologies (BAT). Two technologies have a significant positive influence on the environmental impact of TVs; Light Emitting Diodes (LED), used by Samsung, and Hot Cathode Fluorescent Lamp (HCFL), used by Sony. Besides this technology, Sony has installed a number of features that helps reduce the power consumption even further. These are a presence sensor that detects movement and body heat, and a light censor, which registers the light in the room and adjust the backlight of the TV accordingly. All investigated TVs based on the new technologies are labelled with the European or the Nordic Ecolabel.

For the study in 2011 it was found that the ecolabelled TVs were not necessarily the most energy efficient TVs. Therefore, the TVs with the lowest on-mode power consumption are presented in Figure 2, regardless if they are labelled with an ecolabel or not. The ecolabelled TVs in the study from 2011 are Samsung 32” and 40”, Philips 42” and 46”. These are all labelled with the European Ecolabel.

Figure 2 illustrates the power consumption of ecolabelled TVs from Samsung, Sony and Philips. It is obvious that the TVs based on these new technologies perform better than what is required by the IM, some of the TVs even comply with the Energy Star criteria of 2012, which are the strictest criteria. Since this study was made twice with a year in between Figure 2 also illustrates the development of the power consumption within this year. It is noticeable that in 2009/10 BAT was considered to be ecolabelled TVs. However, in 2011 in several cases for Sony TV the best performing TVs, in terms of power consumption, were not the ones labelled with an ecolabel. This is an interesting result as it could lead to the conclusion that not even the ecolabels can keep up the pace of the technological development

A new technological development in the time between the two studies is the 3D technology. All TVs from Samsung in 2011 have included the 3D technology. As it is illustrated in Figure 2 even the TVs with the new technology are also easily able to comply with the requirements of the IM. A positive development is the 42” TV from Philips, which nearly consumes half the power compared to some of the TVs with a smaller screen size. This TV is also based on the LED technology and has installed different power saving features such as a light sensor and eco mode [18]. Philips TVs were not part of the 2009/10 investigation, consequently a comparison with the older models of Philips is not possible.

In the preparatory studies of the IM the LED technology was mentioned. The consultancy who prepared the preparatory study did however, not find the technology mature enough to be able to draw conclusions on its power consumption level and its environmental impact [28]. It can therefore be assumed that the technology has not had a significant impact on the requirement setting process. This is not a surprise though, as the LED technology was not on the market, when the preparatory studies began. The question is therefore why the technological development in the case of LED has happened so rapidly. Possibly, the industry did develop the technology faster as an attempt to anticipate the coming IM of the Ecodesign Directive or the development would have happened regardless of the adoption of the Ecodesign Directive. The 3D technology has not been mentioned at all in the preparatory study. In both cases the attention is drawn to the time span from the preparatory study, where the analyses are made on possible requirements of the IM and to the time when the requirements step into force. The process is quite complex and long with involvement of all stakeholders, and the technologies in the TVs can develop significantly faster than what is expected in the IM.

6. Conclusions

In this paper the IM of the Ecodesign Directive are analysed. In particular how the requirements in the IM fit with the theoretical understanding of ecodesign and how ambitious the requirements are compared to ecolabels and the performance of best available TVs on the market.

The status in January 2011 is that eleven IM have been adopted. Many of the IM have a focus on power consumption or energy efficiency only. Other issues regulated are related to water consumption, performance and quality. A strong tendency is found that only the use phase of the products is included. Compared to the theoretical understanding of ecodesign, three conclusions can be drawn:

1. Not all environmental areas are addressed in the IM, which is in contradiction with the concept of ecodesign as defined above, and by the way, also to the scope of the Directive.

2. Only one life cycle phase is addressed, which also contradict with the concept of ecodesign, as all life cycle phases should be addressed.

3. The requirements are in line with the concept of ecodesign when it comes to continuous improvement. As noted, the requirements are gradually tightened to achieve improvements of performance over time.

The comparison of the IM and the European Ecolabel, the Nordic Ecolabel, Energy Star and TCO'06 shows that the ecolabels are significantly stricter than the IM – as they should be – and they include more environmental areas and product life cycle phases in their criteria. One reason for the narrower scope is that the IM only focus on the most important environmental impact. However, in order for the directive to be in line with the concept of ecodesign it is an imperative that more environmental impacts and life cycle phases are considered.

With regard to the IM being less strict than the ecolabels, this is not surprising as they are different types of policy instruments. Ecolabels are meant as an incentive for frontrunner companies, whereas the IM are minimum requirements aiming at excluding the worst performing products from the market. However, there is a large range between the two requirements, especially with regard to the larger screen sizes. First, the IM simply accept the relation between the screen size and power consumption. The European and the Nordic Ecolabel have dealt with this by setting an upper limit of 200 Watts regardless of screen size. Further, looking at the market tendency towards larger screen sizes and at the performance of the best available TVs these can easily comply with the IM and many of the ecolabels. This raises the question: what impact does the IM have at all if the performance of the TVs is way below the requirements?

The study of the TVs on the market shows that all investigated TVs could comply with the requirements of the IM and many of the ecolabels both in 2009/10 and in 2011. As only TVs including BAT are analysed this result is not a surprise. However, it is surprising how low the power consumption is. The TV producers have applied different technologies to obtain these low power consumption values. Samsung and Philips have used LED as backlight, which was assessed to be an immature technology in the preparatory study. This leads to the conclusion that the environmental improvements of TVs seem to be driven by a technology push rather than a regulatory pull. It could though also be the case that the producers have speeded up the development of the LED technology because of future requirements in the IM – future expectations to regulatory demands as a driver. A new technology applied in 2011 is the 3D TV. Even the TVs with the new technology are still easily able to comply with the requirements of the IM. The 3D technology has not been mentioned at all in the preparatory study. In both cases, a conclusion is that the process of Ecodesign Directive and the IM takes too long in the case of televisions, and furthermore the innovation of new televisions is more driven by technology push rather than regulatory pull leading to an improved environmental performance.

Since this study was made twice with a year in between it is also possible to see the development within this year. It is noticeable that in 2009/10 BAT was considered to be ecolabelled TVs. However, in 2011 in several cases for Sony TVs, the best performing TVs in terms of power consumption were not the ones labelled with an ecolabel. This is an interesting result as it could lead to the conclusion that not even the ecolabels can keep up the pace of the technological development.

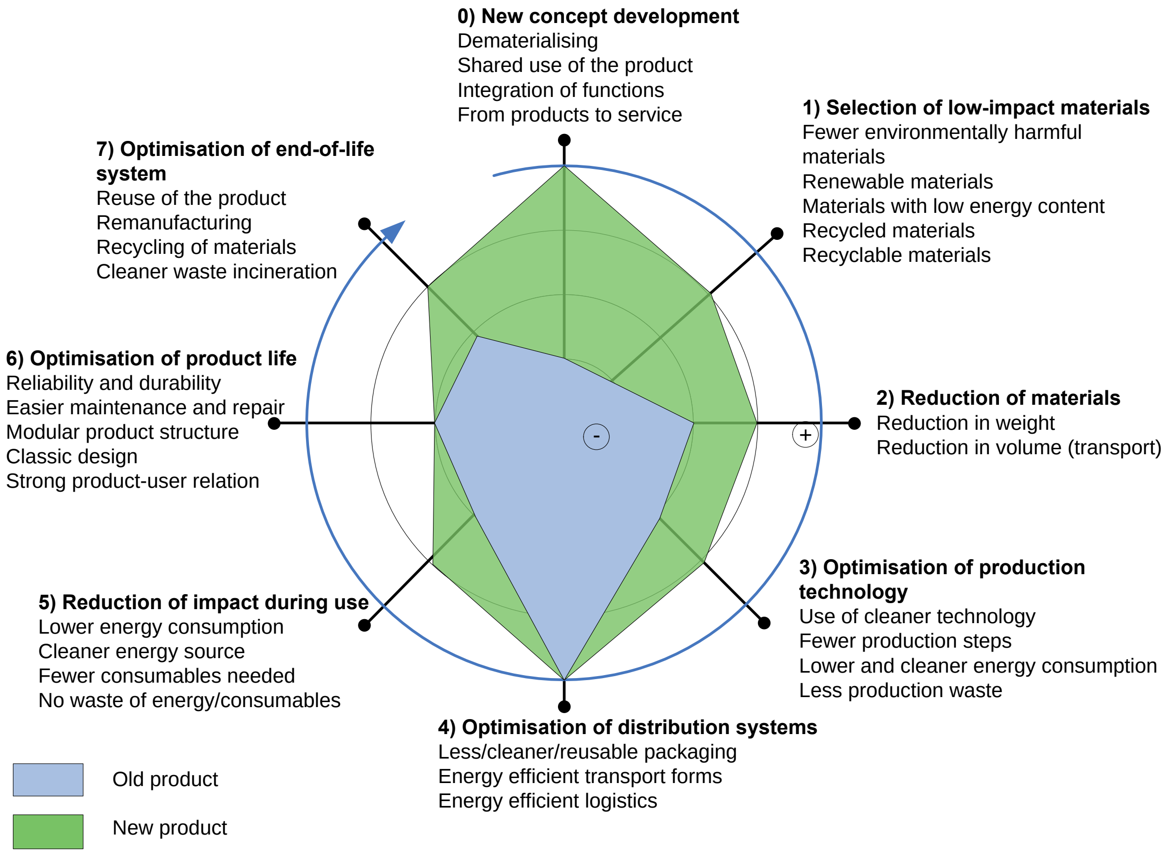


Figure 1: The ecodesign strategy wheel [4].

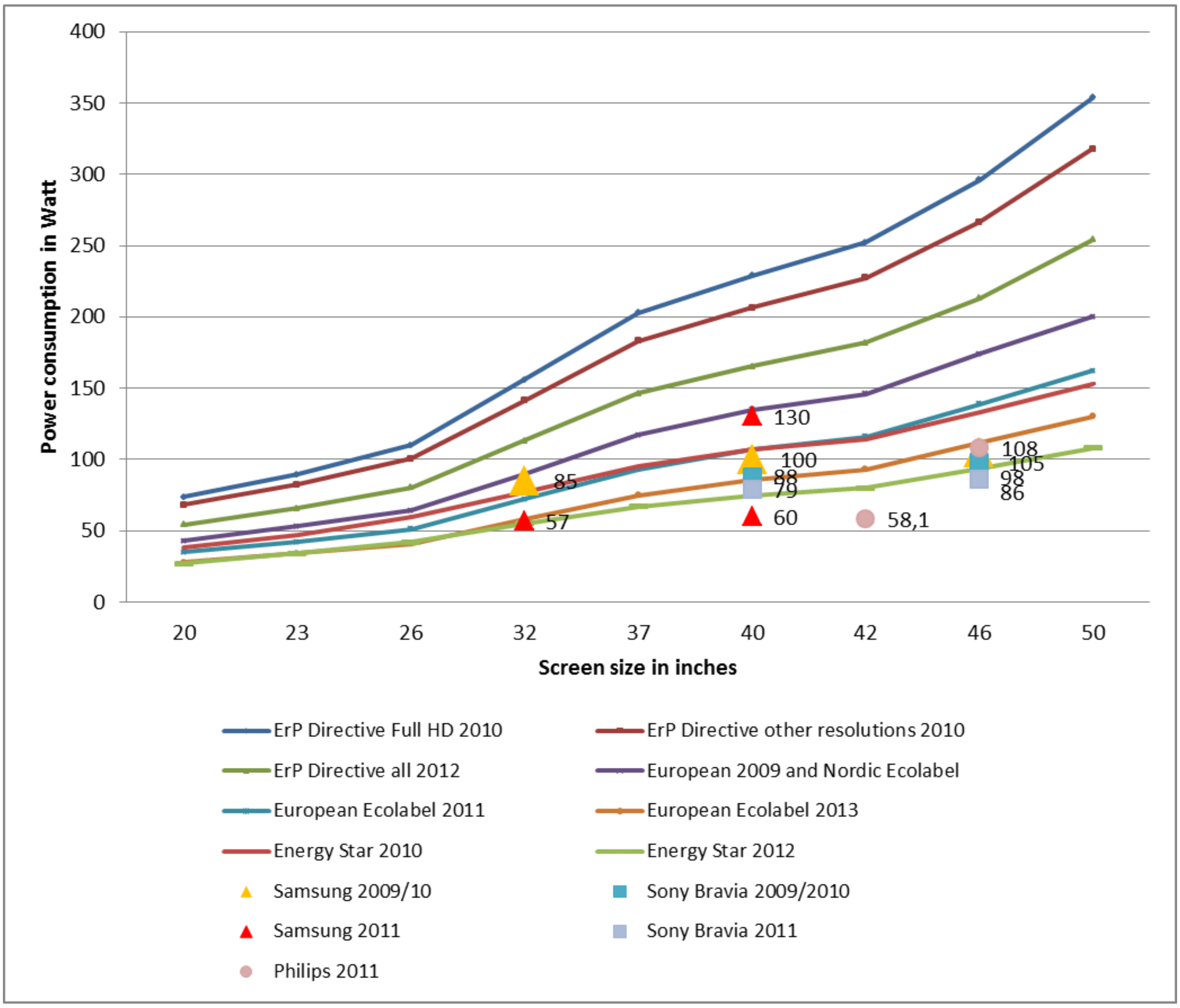


Figure 2: On-mode power consumption requirements of the IM and the ecolabels for TVs and the power consumption of Samsung, Sony and Philips TVs with the BAT [9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

Table 1: Focus area of the eleven adopted IM of the Ecodesign Directive [19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30].

	Entry into force	Adopted	Power consumption	Energy efficiency	Lamp efficacy	Performance	Motor efficiency	Cleaning efficiency	Drying efficiency	Washing efficiency	Water consumption	Washing cycle at 20°	Information requirements
Television	12.08.09	22.07.09	■										■
Standby and off-mode losses	07.01.09	17.12.08	■										■
Battery chargers and external power supplies	27.04.09	07.04.09	■	■									■
Tertiary lighting	13.04.09	18.03.09	■	■	■	■							■
Simple set-top boxes	25.02.09	04.02.09	■										■

Domestic lighting	18.03.09	14.04.09	■		■	■							■
Electric motors	12.08.09	22.07.09					■						■
Circulators	12.08.09	22.07.09		■									■
Domestic refrigeration	12.08.09	22.07.09		■		■							■
Domestic dishwashers	01.12.10	10.11.10		■				■	■				■
Domestic washing machines	01.12.10	10.11.10		■						■	■	■	■

Table 2: Focus area of the IM for TVs and the ecolabels for TVs [9, 10, 11, 12, 19]

Subject	Implementing Measures	European Ecolabel	Nordic Ecolabel	Energy Star	TCO'06
Power consumption on-mode	■	■	■	■	
Power consumption in off-mode	■		■		
Power consumption in passive standby	■	■	■	■	■
Power consumption active standby low				■	
Maximum energy consumption		■	■	■	
General eco-design criteria		■	■		■
Dismantling		■	■		■
Life-time extension		■	■		
Chemicals in products		■	■		■
Information requirements	■	■	■	■	■
Environmental Management system					■

References

[1] European Commission. "Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products", *Official Journal of the European Union,* October 31, 2009.

[2] Tischner, U. *Sustainable Design and Ecodesign*, Design Academy Eindhoven, Eindhoven, 2006.

[3] Tischner, U., E. Schmincke, F. Rubik and M. Prösler. *How to do EcoDesign?* Verlag form GmgH, Frankfurt am Main, 2000. ISBN 3-89802-025-8

[4] H. Brezet and C. van Hemel. *Ecodesign – A promising approach to sustainable production and consumption*. United Nations Environment Programme (UNEP), Paris, 1997. ISBN 92-807-1631-X

[5] I. Zbicinski, J. Stavenuiter, B. Kozlowska and H. van de Coevering. *Product Design and Life Cycle Assessment*. The Baltic University Press, Uppsala, 2006. ISBN 91-975526-2-3

[6] F. Giudice, G. La Rosa and A. Risitano. *Product Design for the Environment - A Life Cycle Approach*. CRC Press, Taylor and Francis Group, Boca Raton, 2006. ISBN 0-8493-2722-9

[7] M. Charter and U. Tischner (eds.). *Sustainable Solutions – Developing Products and Services for the Future*. Greenleaf Publishing, Sheffield, 2001. ISBN 1-874719-36-5

[8] L. Kørnøv, M. Thrane, A. Remmen and H. Lund (eds.). *Tools for Sustainable Development*. Aalborg Universitetsforlag, Aalborg, 2007. ISBN 978-877307797-9

[9] European Commission. "Commission Decision of 12 March 2009 establishing the revised criteria for the award of the Community Eco-label to televisions". *Official Journal of the European Union*, March 28, 2009.

[10] Nordic Ecolabelling. *Nordic Ecolabelling of Audiovisual equipment: Version 3.0 – 17 March 2009 – 31 December 2010*. Nordic Ecolabelling, 2009.

[11] Energy Star. *Energy Star Program requirements for Televisions: partner Commitments Versions 4.0 and 5.5*. Energy Star, 2009.

[12] J. Rudling, and H. Nordin. *TCO'06 Media Displays: Ver. 1.2*. TCO Development, Sweden. 2006.

[13] Samsung Electronics Nordic AB. *This changes everything LED TV: Velkommen til en ny verden*. http://www.e-magin.se/v5/viewer/files/viewer.aspx?gIssue=1&gTitle=LED%20Catalogue%20DK&gYear=2009&gUserID=0&gPaperID=30385&gAvailWidth=1014&gAvailHeight=733&gInitPage=1 (accessed November 10, 2009).

[14] Samsung. http://www.samsung.com/dk/. 2010 (accessed February 5 2010).

[15] Samsung. 2011. http://www.samsung.com/dk/index.html (accessed May 5, 2011)

[16] Sony. Http://www.sony.dk/section/startside. 2010 (accessed February 5, 2010)

[17] Sony. http://www.sony.dk/section/startside 2011. (accessed January 12, 2011)

[18] Philips. *Sense and Simplicity*. 2011. http://www.philips.dk/index.page (accessed January 12, 2011)

[19] European Commission. "Commission Regulation (EC No 642/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and the Council with regard to ecodesign requirements for televisions". *Official Journal of the European Union*, July 23, 2009.

[20] European Commission. "Commission Regulation (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment". *Official Journal of the European Union*, December 18, 2008.

[21] European Commission. "Commission Regulation (EC) No 278/2009 of 6 April 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for no-load condition electric power consumption and average active efficiency of external power supplies". *Official Journal of the European Union*, April 7, 2009.

[22] European Commission. "Commission Regulation (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaries able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council". *Official Journal of the European Union*, March 24, 2009.

[23] European Commission. "Commission Regulation (EC) No 107/2009 of 4 February 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for simple set-top boxes". *Official Journal of the European Union*, February 5, 2009.

[24] European Commission. "Commission Regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps". *Official Journal of the European Union*, March 24, 2009.

[25] European Commission. "Commission Regulation (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors". *Official Journal of the European Union*, July 23, 2009.

[26] European Commission. "Commission Regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products". *Official Journal of the European Union*, July 23, 2009.

[27] European Commission. "Commission Regulation (EC) No 643/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigerating appliances". *Official Journal of the European Union*, July 23, 2009.

[28] Stobbe, Dr. Lutz. *EuP Preparatory Studies "Televisions" (Lot 5): Final Report on Task 6 "Technical Analysis BAT"*. Compiled by Fraunhofer IZM, Berlin. 2007.

[29] European Commission. "Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines". *Official Journal of the European Union*, November 11, 2010.

[30] European Commission. "Commission Regulation (EU) No 1016/2010 of 10 November 2010 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers". *Official Journal of the European Union*, November 11, 2010.

[31] Danish Energy Agency. "Energistatistik 2008". http://www.ens.dk/da-DK/Info/TalOgKort/Statistik_og_noegletal/Aarsstatistik/Sider/Forside.aspx. 2010. (accessed July 29, 2010).

The Danish Energy Saving Label – Consumer-friendly Energy Labelling for Energy Efficient Products

Mads Lindevall Kristiansen

Project Manager, The Danish Energy Saving Trust

Abstract

Energy labels are designed to guide consumers to buy energy efficient products. However, the making and revision of a new EU regulation is a very comprehensive process, often taking years to implement. Another issue is that many energy consuming product groups are not as yet covered by any recognized recommendations or regulations. Although product development is rapidly improving the performance of new products to make them more and more efficient, the energy efficient choice is often not that simple in practice.

This paper describes the evolution of the present Danish Energy Saving Label, which was conceived following the successful implementation of a subsidy campaign in the late 1990s to encourage Danes to switch to energy efficient refrigerators. The paper discusses the thinking behind the label, and its historical use based on voluntary agreements; the philosophy underpinning the future use of the labelling scheme following the transformation of the previous organization into the Danish Energy Saving Trust (Go' Energi); the development of the labelling criteria, and the use of campaigns; and the random testing regime to maintain the credibility of the label.

The Danish label dovetails, rather than competes with EU schemes. Five years after its introduction, the label is one of Go' Energi's most important areas of activity in its drive to make it easy for Danes to choose energy efficient products. In this respect, it appears that the label has become an effective catalyst for increasing market share of the most energy efficient products. Furthermore, industry association and producers have recognized that the simple and flexible character of the label can be easily transferred to other product groups.

Introduction

12 years ago the role of the then Danish Electricity Saving Trust (the Trust) was very different to the one fulfilled by the Danish Energy Saving Trust (Go' Energi) today[1].

In 1998, the Trust was established to distribute the funds at its disposal to encourage Danish householders using electric heating in areas where district heating or natural gas supplies were available to convert to cheaper and more environmentally friendly forms of heating,.

In short, in the late 1990s and early 2000s, the Trust's primarily acted as a provider of subsidies to enable Danish households to replace their old electric heating systems at an affordable price.

Within the remit established by the original act of parliament, the Trust was also able to identify other key areas to which the subsidy concept might be applied. One such area was domestic refrigerators or fridges.

However, the introduction of the label took six years from conception to inception.

[1] The Danish Energy Saving Trust (Go' Energi) is expanding the activities of the former Danish Electricity Saving Trust (The Trust) and is now responsible for promoting savings for all forms of energy, excluding transport, in the household, public and industrial and commercial sectors. Established on 1 March 2010, Go' Energi is an independent, public sector organisation with its own Board appointed by the Minister for Climate and Energy.

Subsidy schemes pave the way for first Electricity Saving Label

In 1998 there were very few A-rated fridges sold, and the market for energy efficient refrigerators in Denmark was small – accounting for less than 7% of total sales.

In consultation with producers, the Trust identified an opportunity to boost these sales by offering a DKK 500 subsidy to both domestic and public sector consumers towards the purchase of an A-labelled energy efficient fridge.

The programme, which was implemented in partnership with producers and the relevant trade associations representing the importers, distributors and retailers of household appliances, was based on a pilot scheme followed by a series of short-duration campaigns. The subsidies, which were paid by the distributors of the products directly to consumers, were either funded by allocations approved by the Danish parliament specifically for the purpose, or were provided by the then Danish Electricity Saving Trust via additional funding from the Danish government.

The pilot scheme, which initially ran for 13 weeks, was an instant success and paved the way for a succession of similar campaigns from 1999 to 2005. These helped expand the range of A-labelled fridges on the market and boosted sales volumes, with the result that by 2007 almost 97% of all fridges purchased in Denmark were energy efficient. It could be argued that the increased penetration of energy efficient fridges in Denmark would have occurred anyway, in line with the general EU trend. Although no formal research was conducted at the time, the feedback from international producers was that market share for energy efficient products was much greater in Denmark compared with other countries in the EU. The Trust considered this more rapid uptake of energy efficient products to be directly attributable to the subsidy campaigns.

It was during a subsequent evaluation of the scheme that a manufacturer suggested the idea of developing a recognizable graphic symbol which distributors and retailers could use to identify energy saving products, thereby differentiating them from the less efficient products on the market. It took, however, a further six years of discussions of the pros and cons of such a scheme before the Trust could launch the first Danish Electricity Saving Label.

The advantages were clear: A local label that encouraged Danish consumers to buy energy efficient products on the basis of a recommendation from a non-partisan body would clearly help to increase the sales. On the other hand, producers were wary of a scheme which would clearly reduce their sales of less energy efficient versions compared with products endorsed by the Trust. The producers, supported by the EU, also objected to any possibility of the label being mandatory.

In the end a balance was struck, and the Danish Electricity Saving Label came into being as a scheme implemented in partnership with the producers, distributors and retailers on the basis of voluntary agreements covering the 20-25% most efficient products on the market for any given product group [1]. The source of information covering sales share varies from product group to product group. For example, statistics about large domestic appliances (white goods) are collected from FEHA (Danish Association of Manufacturers and Importers of Electrical Appliances). Go' Energi also collects sales figures from organization that are not members of FEHA, for example chains that import products directly. Information about lighting products is not available from trade associations, and in this case, Go' Energi relies on the figures supplied by individual producers and importers.

Simple, safe and cheap

The Trust's original thinking behind the Energy Saving Label was to make it simple, safe and cheap for consumers to purchase energy efficient products on the market [2].

Figure 1. Danish Energy Saving Label (*EL* means electricity in Danish).

To ensure that the label made an impact on the market, efforts were focused on helping make the buying public aware of its existence. Consumers had to know that the label would be their guide to finding energy efficient products.

The former Trust traditionally put a lot of effort into campaigns that informed the target groups about the function of the label. Furthermore, in its current campaigns Go' Energi always refers to the EU 's mandatory energy labelling schemes.

Use of the Energy Saving Label governed by voluntary agreements

Use of the labels for marketing of recommended products was, and continues to be subject to Product and User agreements implemented by the Danish Energy Label Secretariat. Under these agreements, the user must meet the requirements covering the use of the labels.

Several players can conclude an agreement to use the label:

- Producers/supplier which produce/import/supply products recommended by Go' Energi
- Distributors: Stores, wholesale societies and retail chain stores distributing the recommended products
- Others: Trade organisations, wholesalers, electricity supply companies, etc.

New name ... new era

There have been many changes since the first 'Electricity' Saving Label was launched in 2006, with the most significant development being the launch of the Danish Energy Saving Trust (Go' Energi) in March 2010. Instead of electricity alone, Go' Energi now focuses on energy savings for all forms of energy, other than transport.

In terms of the resources at its disposal, Go' Energi is financed by a special energy saving charge payable by households and the public sector with annual proceeds amounting to about DKK 90 million disbursed by a Secretariat of around 13 staff. The Danish Energy Saving Label programme is run by a separate outsourced Energy Saving Label Secretariat employing 3-5 staff.

In keeping with the broader remit, Go' Energi has recently published its 2011 Energy Action Plan [3] which lays out the strategy that Go' Energi will adopt. One result of the organisational change is that the old label has been redesigned as is now called the Energy Saving Label.

Figure 2. The new-look Energy Saving Label

The Danish Energy Saving Label – 2010 and beyond

The label has come a long way from its inception based on discussions stemming from an evaluation of a subsidy scheme designed to encourage consumers to buy energy efficient fridges in 1998.

Today, the Energy Saving Label has evolved into a successful voluntary labelling programme for electrical appliances and solutions on the Danish market. With the exception of dishwashers (label coming in 2011) and ovens (no label currently planned), the scope of the Danish label has been expanded to cover:

- A-rated energy saving bulb
- Heat pumps (air-to-air, air to water, geothermal (ground source)
- Central heating circulator pumps
- Computers
- Computer monitors
- Photocopiers, printers and scanners
- Set-top boxes
- Energy saving equipment
- External power supplies
- Fridges and freezers
- Tumble dryers
- Washing machines
- Wireless devices [4]

Four strategic pillars

Go' Energi faces many different types of barriers in different sectors – all presenting very different challenges. In order to tackle the barriers and challenges, Go' Energi has identified four strategic pillars that describe methods to tackle them, namely:

- making it easy to choose energy efficient solutions, products and processes
- making it easy to act in an energy efficient way
- making it easy to implement energy improvements in buildings
- making it easy for other actors to promote energy efficient solutions.

'Making it easy' means that Go' Energi will help to create a solid foundation on which energy users can base their decisions in respect of their own energy consumption, and how the system is constructed and operated. Energy users should be able to take rational decisions based on a minimum of time, and a maximum of trust. This is the only way to get a broad cross section of consumers in both the private and public sectors to unlock the potential that exists for making financially viable energy efficiency improvements [5].

Choosing energy efficient solutions, appliances and processes

The first and last of these four pillars are particularly important when targeting consumers in terms of the Energy Saving Label. How can Go' Energi help purchasers identify their real needs, and choose the right energy efficient solutions?

To start with, when the time comes for purchasers to buy new appliances, it is important to point out that, although they may cost more initially, energy efficient equivalents are always cheaper in the long run because lower energy consumption will more than compensate for the possible higher investment cost. It is worth remembering that when consumers buy an appliance they are also buying an energy bill over the lifetime of the device.

In order to identify the possibilities, prospective purchasers need to be able to see what is available. In the jungle of appliances on the market, they also require an overview with information about the appliances' functions, product quality, and also energy consumption. Go' Energi must help create, maintain and publicise these overviews (or lists) for the areas that can make a significant difference. The Energy Saving Label fits perfectly into this strategy [6].

Who benefits from the use of the Danish label?

By agreement, producers, distributors and retailers may use the Energy Saving Label, at no cost to themselves, on products that comply with Go' Energi's requirements.

Labelling criteria

Product groups need to comply with four basic requirements in order to display and benefit from the Danish label:

- products/solutions must be available to private consumers
- products/solutions must be energy efficient or energy saving. The term energy efficient refers to products or solutions that save energy directly (e.g. A-rated fridges, light bulbs, etc.), whereas energy saving may also describe products that promote energy awareness, not necessarily using energy while doing so (e.g. windows, thermostats, on/off timers, etc.). Although the energy efficiency requirements vary from product group to product group, the overall condition applying to the use of the label is that products must save energy
- the energy efficiency or energy saving properties of the products/solutions must be identifiable and verifiable in an objective and recognised way
- the product category must have a considerable energy saving potential, or products/solutions must be innovators within their field in a way that directly or indirectly triggers energy savings or energy conscious behaviour (e.g. new technologies), or
- the products/solutions must demonstrate that they are being heavily advertised and promoted, thereby resulting in the label being more prominently featured.

In some cases Go' Energi lays down requirements that exceed the specifications of the equivalent mandatory EU energy label. This is usually because there are other factors that are important for the use of the product which have an impact on the energy consumption. A good example is heat pumps, where the specifications cover their operation in the Nordic climate. The Nordic countries have also differentiated themselves at a very early stage from southern European countries by laying down specific colour requirements for A-rated energy saving bulbs.

Labelling criteria are developed in partnership with producers

When requirements are developed for a new product/solution, the process is always based on international schemes (e.g. EU mandatory labelling scheme for household appliances and light sources, etc.), and on voluntary schemes such as Energy Star.

From the outset, involving all parts of the supply-side chain (e.g. producers, industry associations, etc.) is very important, which is why these bodies are invited to comment on the draft requirements at a very early stage of the process. Ideally, Go' Energi endeavours to create voluntary agreements where all producers agree to the requirements covering the use of the Danish label, and indicate their willingness to support campaign activities planned in connection with the launch of the label.

Cooperation by producers, and their willingness to sign voluntary agreements, varies from product category to category. Some industry associations have waited a long time for a label covering the products/solutions they represent. Typically, these tend to associations with members that sell similar types of products such as high-end brands. On the other hand, there are associations representing industries with very different goals and ambitions (e.g. those representing producers that both focus on low price/low quality and others that prioritise high price/high quality). This means that it is often very difficult to produce an agreement that is broad enough to cover the interests of all members.

In this situation, and on the basis that some industry associations are not willing to enter an agreement, the process of developing a label continues with only the producers who want to cooperate.

Recipe for success

The success of the Label is based on three key factors:

1. The label criteria are developed in partnership with producers.

2. Campaigns are run with close cooperation of the producers/distributors/retailers to increase consumers' awareness of the label, supported by targeted, media-specific advertisements.

3. Random testing of products bearing the Label is carried out regularly to maintain the Label's credibility in the minds of the consumers and buyers.

As previously mentioned the Danish label is intended to cover the 20-25% most efficient products on the market for any given product group. If this figure is exceeded, Go' Energi takes steps to re-evaluate the qualifying requirements in a dynamic process that follows the development of products in the marketplace.

New requirements are developed on the basis of already existing specifications or requirements. For example, the requirements for fridges/freezers and lighting are based on the EU energy labelling schemes. The specifications for IT equipment are based on Energy Star. In addition, all the qualifying requirements are discussed and evaluated by experts in the respective fields, or by selected producers and distributors of the products on the Danish market, and possibly also by trade associations and the Danish Energy Agency, etc.

Campaigns with all parties involved

The manufacturers, importers, suppliers and distributors are informed about the launch once the requirements are in place – typically at meetings with the largest suppliers and distributors on the market. Apart from briefing them about the launch details, the purpose of the meetings is to:

- Take soundings on the best and most efficient way of implementing the campaign(s)

- Persuade all the participants to get involved and support the use of the Energy Saving Label.

Because the participants have years of experience in selling the specific products on the market, and know exactly what is realistic and what works, it is vital that participants can make suggestions concerning the launch strategy.

Different markets require different solutions, which is why Go' Energi has a line of tools that can be used, for example, in situations where a participant chooses to take a different approach to promote energy savings. Naturally, Go' Energi is also able to arrange press coverage of any initiatives taken. A range of measures is available to participants. Amongst others. These measures include "Curve Breaker Agreements", "Recommended Retailer Agreements" and "Range Agreements". Notwithstanding, it is generally true that the more efforts participants make to promote efficient products, the more Go' Energi can do to support the participants' efforts.

Once all the views of the participants have been collected, the campaign is modified accordingly before being presented to the target audience(s).The campaign mix can vary with some campaigns using PR to feature a website for example, with others relying on a large-scale TV advertising campaign.

Moving market share – the circulator pump campaign

The campaign to promote "smart" energy efficient central heating circulator pumps is one the best examples of how the Danish label contributed to "moving" the market share for these pumps [7], [8].

Before 2004, most circulator pumps had an energy efficiency corresponding to Energy label D [9]. The Danish producer Grundfos had tried to introduce a C-rated pump a few years previously but despite active marketing these pumps only achieved a 20% market share.

Nonetheless, the former Trust believed that it would be possible to increase market share, so in 2004 it signed a voluntary agreement with manufacturers of pumps, suppliers, and plumbers and installers to establish a campaign over three years. The purpose of the campaign was to move the market share of pumps in energy class C or better from 20% to 75%.

In order to achieve this goal, the Trust publicised the fact that C-rated pumps only used half the electricity used by D-rated pumps. This information was supported by

- Direct marketing targeted at plumbers and installers
- Offers from manufacturers and suppliers to consumers.

The industry was very cooperative and welcomed the campaign with open arms, thereby providing consumers with the ideal basis for investing in C-rated pumps. So much so that the campaign goals were fulfilled after only 2 years.

"C" to "A"

In 2006, a further agreement was made to cover the development of even more efficient A-rated pumps. Before the campaign it was estimated that approximately 1.2 million households in Denmark had a circulator pump and that 800,000 of them were not energy efficient. Potentially, 400 GWh per year could be saved by Danes switching to A-rated circulator pumps.

The campaign was designed in the same manner as the campaign in 2004 and like the previous campaign, the results were excellent. The Trust and its partners managed to increase the market share for the most efficient circulator pumps, boosting the number of A-rated circulator pumps in Danish households from 15% in 2006 to 60% in 2008.

This change can be viewed in the figure below:

Figure 3. Development of market share for A-rated pumps

General campaigns and activities

Since the launch of the original label in 2006 the following campaigns and activities have been carried out:

- 2006–2009: periodic campaigns supported by TV advertising, web banners, print advertisements, PR, radio spots, etc.
- Development of in-store materials, with comprehensive information that can be used outside campaign periods.
- Entering into agreements with manufacturers and distributors regarding the use of the label, which normally requires them to submit individual sales volumes. Alternatively, these figures can be provided by a trade association covering the entire market.
- Establishing, maintaining and updating product overviews for the recommended appliances on Go' Energi's www.goenergi.dk and www.savingtrust.dk websites.
- Development of specially tailored advice and information for use in retail marketing materials and on websites.

Results of campaigns and activities

- 2008: Evaluation of the former Trust's efforts targeted at Danish households, including activities involving the use of the Energy Saving Label, concluded that 82% of consumers believed the Danish label to be credible.
- 2009: Research indicated that 74% of Danes had heard about, or were aware of the label. Also, that partners involved with the label were pleased with the results and the label's value-enhancing benefits. To date, more than 2,000 producers and retailers have signed agreements covering their use of the label.
- 2009: Random testing confirmed that the label was used in about 34% of the retail stores that have agreements with the former Trust. This was positive, considering that the in-store materials have a normal shelf-life of 6 weeks.

Today, Go' Energi monitors the use of the label in two different ways. One method involves checking the in-store uses of materials. The other method is checking the suitability of products before they are included on Go Energi's lists of recommended products bearing the label.

Regular random testing of stores

Once a year Go' Energi's Energy Label Secretariat checks the use of materials in the stores to ensure that the materials are being used correctly and are not misleading consumers. The checks involves ensuring that the labels are only affixed to products that appear on the Go' Energi's lists of recommended products. The results of these checks are communicated to the stores in question, or to the head office of stores that are part of a chain. Stores using the material incorrectly are instructed to remove the label from products that are not recommended by Go' Energi.

In extreme cases, stores failing to comply may have their agreements terminated. However, as a result of the positive partnerships with Go' Energi this sanction has never been used.

Random testing of recommended products

Each year Go' Energi carries out random tests to ensure that the Energy Saving Label is used exclusively on recommended products. These tests comprise different products in different product categories, and are carried out on the basis of the principles and methods recommended by the Danish Energy Agency which is responsible for supervising and implementing EU mandatory labelling schemes.

Product experts from each field sample the products to be tested. Under a Producer's Declaration, each producer is obliged to make products available free of charge for testing by Go' Energi, but in practice Go' Energi gets the products from a distributor so that the producer cannot influence which products are selected.

The test is performed by impartial, recognised and accredited analytical laboratories within this field. Go' Energi meets all the costs involved in the testing process. However, under the Producer's Declaration, if a product fails the test, the producer can be ordered to pay the costs involved.

Following the test or tests Go' Energi's Energy Label Secretariat informs the producers or suppliers of the results. In the event of a product failing the test the supplier has two options: Accept the result, or request the product model be retested on the basis that the producer can document any irregularities in the results. The supplier is liable to pay all costs in connection with the additional test if the retest confirms the original results.

Results of the random testing are published to provide consumers with the opportunity to complain about their purchase. Producers or suppliers also have the right to comment on the test results. The number of products that fail can vary enormously. Some random tests result in no failures, whereas others result in many failures. In the case of the latter Go' Energi's Energy Label Secretariat increases the frequency of the random tests as a preventive measure, and also cooperates with the relevant trade association and the Danish Energy Agency to avoid the reoccurrence of a similar situation in the future.

If a product fails, it is no longer authorised to use the Energy Saving Label. All distributors of the product are informed and are requested to remove the label from the product as soon as possible.

Ad-hoc testing

Apart from annual random testing, the Energy Saving Label Secretariat carries out a series of ad-hoc tests on products not covered by the Danish voluntary labelling scheme. These tests provide an indication of the energy consumption for a product category that Go' Energi may be planning to include in the scheme in future.

Currently Go' Energi is in the process of testing TVs and LED light fittings with a view to establishing the labelling criteria for these two product categories in the future.

Ad-hoc testing is also used to test popular new types of energy consuming appliances on the market, even if there are no immediate plans to introduce the Energy Saving Label to the products. Products previously tested under this heading include game consoles, plug and pour all-in-one beer chillers for household use, and Quookers (boiling water taps).

Ad-hoc testing can also identify poor-performing products providing consumers with information that can help them choose the most energy efficient solution in the long term. One recent example of this type of testing was cheap air-to-air heat pumps advertised as being suitable for use in Danish holiday homes.

Conclusion

The Danish labelling scheme dovetails, rather than competes with the EU arrangements. Five years after its introduction, the Danish label has become an important tool for steering consumers in Denmark in the direction of energy efficient products.

As previously mentioned, Go' Energi maintains the credibility of the label by carrying out random testing to ensure that products conform to market requirements covered by the label. These activities take place in close cooperation with the Danish Energy Agency which is responsible for supervising and implementing EU mandatory labelling schemes.

In its 2011 Action Plan, Go' Energi describes the Danish Energy Saving Label as its most important initiative for making it easy for consumers to choose energy efficient products.

However, until 2011, the Danish label focused exclusively on products and solutions that saved electricity, but in keeping with its new role Go' Energi will be expanding its activities to take account of the large savings potential in buildings. In the first instance, Go' Energi will be focusing on products, for which standards already exist, and which offer the best potential savings.

Go' Energi is therefore planning to develop criteria for a label covering at least one product category related to energy efficiency in buildings. Looking ahead, Go' Energi is planning to introduce several new product categories over the next 3-5 years.

In tandem with the introduction of the label for new product areas, it will also be necessary to phase out the label for other product categories. In future, Go' Energi will prioritise its efforts on the basis of how much impact the label has on a particular market, rather than using its resources on areas that show little return.

Last but not least, in keeping with its new role and name, Go' Energi is in the ideal position to further consolidate and develop the impact and the credibility of the Energy Saving Label. In this connection, Go' Energi launched a campaign in spring 2011 based on the theme that the label makes it easy to choose energy efficient products. Apart from maintaining consumer interest in the label, the campaign also previews new products within the room heating and building envelope categories.

The campaign will also highlight the cooperation with the Danish Energy Agency in connection with the introduction of the new EU energy labelling scheme with its new rating scale up to A+++.

Finally, the latest informal survey of the label's credibility revealed that 71% of respondents believed that the label played some part in their decision making process, with 82% confirming that they found the label to be credible.

Go' Energi's goal is to maintain this position.

References

[9] Europump (2005) *Industry commitment to improve the energy performance of stand-alone Circulators through the setting-up of a Classification Scheme in relation to Energy Labelling*. http://www.europump.org/ [7] Lüders, Christian (2009): *Campaign for A-rated circulator pumps – a proven strategy*. ECEEE 2009 Summer Study (June 2009). ISBN 978-91-633-4454-1. www.eceee.org

[2] Rasmussen, Sanne (2009): *The Danish Energy Saving Label – Consumer friendly energy labelling for energy efficient products*. ECEEE 2009 Summer Study (June 2009). ISBN 978-91-633-4454-1. www.eceee.org

[8] The Danish Electricity Saving Trust (2008): *A-rated pumps*. http://www.savingtrust.dk/consumer/products/indoor-environment/a-rated-pumps.

[1], [4]The Danish Energy Saving Trust (2010): *The Energy Saving Label is the easy route to energy saving products*. http://www.savingtrust.dk/consumer/here-is-how-to-save/energy-saving-label

[3], [5], [6] The Danish Energy Saving Trust (2011): *Handlingsplan 2011* (only in Danish)

Proposal for a New Energy Label

Jørgen Schjær-Jacobsen

Dept. of Civil Engineering, The Technical University of Denmark

1 Abstract

Energy labeling is believed to have great impact on the energy efficiency of household appliances sold. Many different labeling schemes exist around the world. As far as is known, none of these facilitates the easy tightening of specifications to keep up with technological advancements.

The present proposed labeling scheme is simple and eliminates the above problem. The label simply consists of a *year*. That year would represent the year in which the performance of the product in question is/was state of the art. Each year the authorities would define the requirements for next year's label. It should be easily understandable by everybody: the more recent the year the better the product.

The scheme readily lends itself for an almost unlimited variety of products, and would also cover properties other than energy consumption. It is always up to date, it is globally applicable, and it encourages manufacturers to continually improve their products.

2 Examples of Existing Energy Labels

Many existing labeling schemes seem to have been designed without *dynamic labeling* in mind, i.e. the revision at regular intervals to keep up with technological advancements. If labeling is not kept up to date manufacturers are not encouraged to improve their products, and consumers cannot rely on the labeling to select the better product.

As it became inevitable existing labeling ranges have been extended essentially in two ways:

- Extending scales by adding more grades
- Tightening specifications for existing grades

Below a few examples of existing labels, selected at random, will be presented, some of them with extensions.

Figure 1 shows a Singapore energy label for an air conditioner. The energy efficiency is denoted by

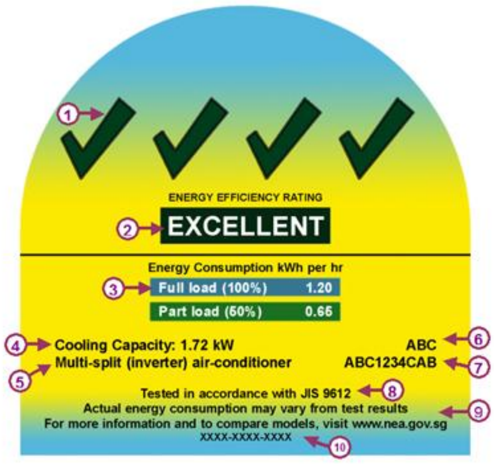
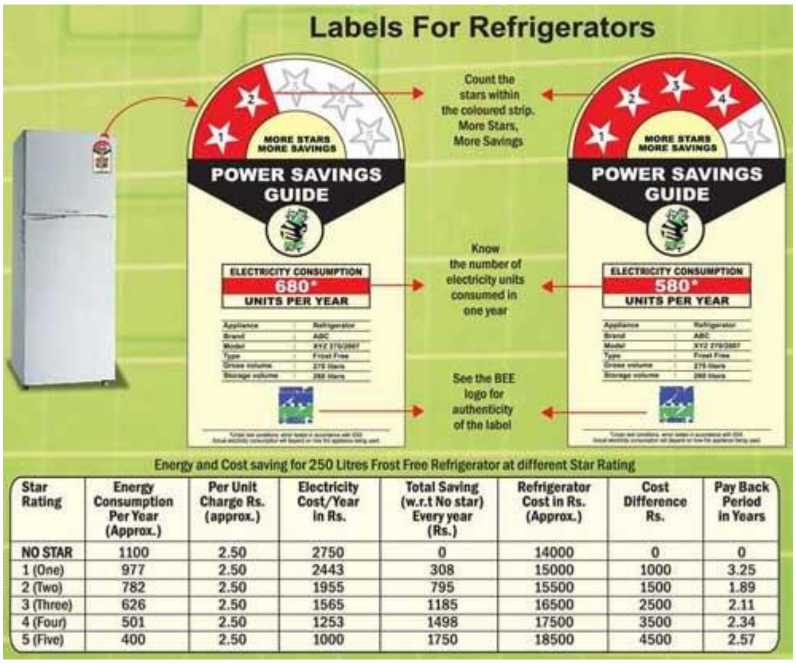


Figure 1. Singapore air conditioner energy label



Star Rating	Energy Consumption Per Year (Approx.)	Per Unit Charge Rs. (approx.)	Electricity Cost/Year in Rs.	Total Saving (w.r.t No star) Every year (Rs.)	Refrigerator Cost in Rs. (Approx.)	Cost Difference Rs.	Pay Back Period in Years
NO STAR	1100	2.50	2750	0	14000	0	0
1 (One)	977	2.50	2443	308	15000	1000	3.25
2 (Two)	782	2.50	1955	795	15500	1500	1.89
3 (Three)	626	2.50	1565	1185	16500	2500	2.11
4 (Four)	501	2.50	1253	1498	17500	3500	2.34
5 (Five)	400	2.50	1000	1750	18500	4500	2.57

Figure 2. Indian energy labels

zero to four check marks; the more check marks the better. It is not known if and how extensions are planned [3].

The Indian refrigerator energy label (Figure 2) features a one to five star scheme; the more stars the better. It is not known whether or not plans exist to extend the range [4].

The Chinese label (Figure 3) resembles the European A...G label, except the grades are numbered 1 to 5, where in this case 1 denotes the more efficient product. It is not known if and how extensions are

Figure 3. Chinese energy label

planned [5].

The Building Energy Rating (BER) adopted in Ireland is shown in Figure 4. It includes no less than 13 grades: A1, A2, A3, B1, B2, B3, C1...F, G. It would be more easy to grasp (though less colorful) could it be expressed as a single year. It is not known if and how extensions are planned [6].

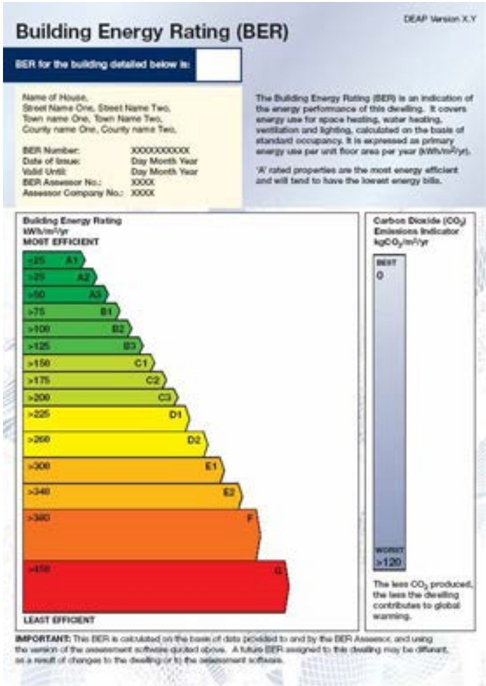


Figure 4. Building Energy Rating

The American Energy Star (Figure 5) is an example of a label without any grades. A certain product either earns the Star or it doesn't. The requirements are not very strict. They are generally only tight-

Figure 5. The American Energy Star label has no grades

ened once Star qualified products in a particular category exceed a market share of 50% [7]. Thus there isn't much incentive for manufacturers to improve their products, nor for consumers to select the better product.

The Thai energy label, shown for an air conditioner in Figure 6, is graded 1 to 5. In this case the higher number denotes the more energy efficient product. The proposed updating principle is keeping grades

Figure 6. Thai energy labels. The label to the right was updated in 2006.

but adding a year that defines when the specifications were updated. In the figure the label to the right has had the year "2006" added [8]. A similar measure has been proposed for the European label. The user has no way of knowing whether or not an old grade 5 is better than a new grade 4.

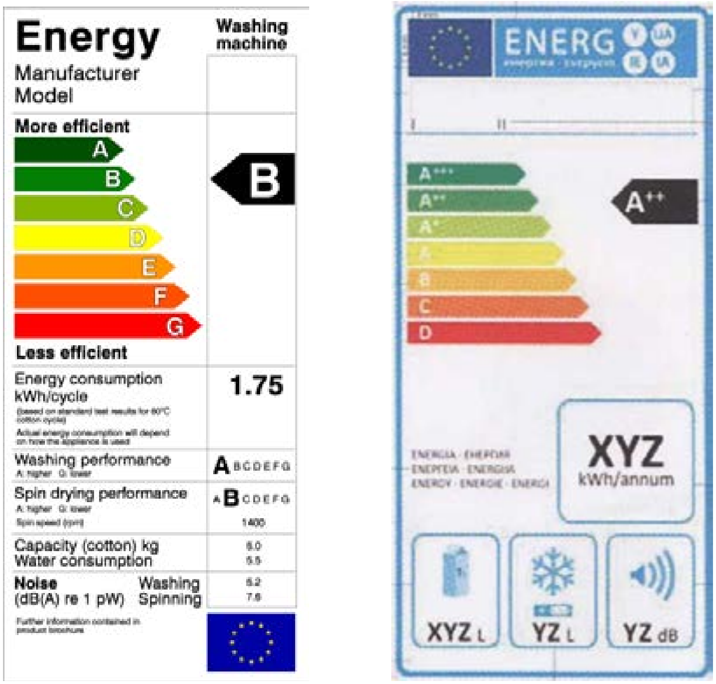


Figure 8. Ordinary and extended European energy label

The Australian 6-star energy label (Figure 7) has been extended by a 10-star label featuring 4 "super efficiency" ratings, gaining some respite. The more stars the better [9].

The ordinary EU energy label is shown in Figure 8, left, for a clothes washer. It features a 7-grade scale A through G, where A denotes the better product. This scale has been extended for certain ap-

Figure 7. Australian 6-star and 10-star energy labels

pliance types by adding three new grades: A+, A++, and A+++, and eliminating the grades E, F, and G (Figure 8, right) [1]. In this way a couple of years' respite has been obtained, at the same time adding to user confusion.

Figure 9. The European A rating is not up to date

Figure 9 is taken from a recent Danish advertisement. It is an example of a manufacturer pointing out that the advertised dishwasher, among other things, consumes 10% less energy than required for a European A grade. It proves that energy labeling in this case is not up to date.

3 Future Energy Labels

When the European A+++ label becomes obsolete, should it be extended to something like the one suggested in Figure 10? The user might have difficulties counting the plusses.

Figure 10. Future EU energy label?

Figure 11 shows a rival for the new scheme proposed in this paper, a label proposed by CECED (Conseil Européen de la Construction Electro-Domestique, European Committee of Domestic Equipment Manufacturers). The grades are numbered 1 through 7, where in this case the higher number denotes the more energy efficient product. In the future, when improvements occur, the grade "1"

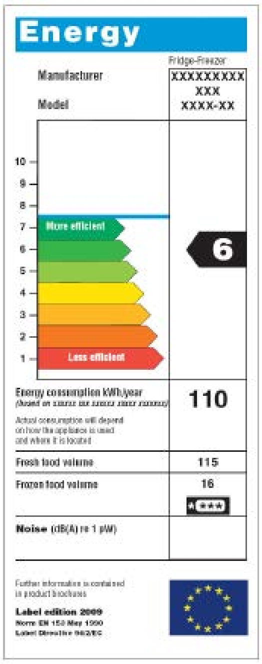


Figure 11. Extendable label proposed by CECED

would be eliminated and a new grade "8" added, etc., *ad infinitum* [2]. Thus this scheme presents an effective solution to the problem how to adapt to future requirements. However, the lay user has no way of knowing which grade currently represents the state of the art.

4 New Proposed Energy Label

The new label proposed in this paper simply consists of a *year*. That year would represent the year in which the performance of the appliance in question is/was state of the art.

Each year the authorities would determine how much next year's requirements should be tightened compared to those of the current year. The degree of improvement would be defined by the current rate of technological advancement. One should attempt to always be slightly ahead of time, so that only on rare occasions will a product appear on the market that carries the current year on its label. In other words, the requirements of next year's label should be defined to somewhat exceed the performance that is expected to appear on the market during that year. In that way there is always room for manufacturers to improve the labeling of their products.

This labeling scheme is simple and expected to be easier to understand by everybody than most existing labels: the more recent the year the better the product. For instance, a refrigerator labeled "2009" would perform at least like the most efficient refrigerators available in 2009, one labeled "2010" would be somewhat better, and so on.

The scheme readily lends itself to a variety of products, like electric and electronic equipment, cars, tires, buildings, lighting, heating, cooling, ventilation, doors, windows, etc., and would also cover properties other than energy consumption, e.g. performance, environmental impact, safety, and ergonomics.

It is believed to be globally applicable, except maybe in places where people cannot read a year number. Adjustments may be necessary to adapt to calendars other than the Gregorian.

A simple example of a washing machine label according to this idea, based on the ordinary European label, is shown in Figure 12. It is illustrated how some properties, like water consumption, are graded individually. An actual label should of course be rendered more aesthetically appealing by a capable

Figure 12. Example of new proposed energy label for a washing machine

artist, maybe adding a flower, green Earth, or other pleasant symbol.

5 Conclusion

As far as is known no existing energy labeling scheme is well suited for dynamic labeling, at the same time being easily understandable by everybody. This has been shown for a number of existing and proposed schemes. (Of course there is still a chance that such a scheme does exist without the author's knowledge).

Conversely, the topical proposed scheme

- Is always up to date
- Is easily understandable by everybody
- Covers a variety of products
- Covers a variety of properties
- Is globally applicable
- Encourages manufacturers to improve their products
- Encourages consumers to pick the best available product

6 References

[1] *Household appliances: energy consumption labelling (until 2011)* http://europa.eu/legislation_summaries/consumers/product_labelling_and_packaging/l32004_en.htm

[2] *Revision of the EU Energy Label layout; ANEC views and arguments* http://www.taenk.dk/upl/cms/1/2271_ANEC-ENV-2008-G-017.pdf

[3] Singapore National Environment Agency: *The Energy Label* http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2844

[4] Ministry of Power, Govt. of India: *Switch to Electrical Appliances With BEE Label* http://www.emt-india.net/Standards_Labeling/Posters/BEE-HTAdvertisement26Mar2008.pdf

[5] Ecolabel Index: *China Energy Label* www.ecolabelindex.com/ecolabel/china-energy-label

[6] *Building Energy Rating (BER) Scales* http://www.buildingenergyireland.ie/BERCerts1.html

[7] *About Energy Star* http://www.energystar.gov/index.cfm?c=about.ab_index

[8] Srinual Soksod and Panu Suwicharcherdchoo: *Rescaling the Energy Label No.5: 2006 version in Thailand* http://www2.egat.co.th/labelNo5/article/D_art/panu_eng%201.pdf

[9] *Sample of the Australian Energy Labels for Refrigerators and Freezers* http://www.energyrating.gov.au/rf5.html

Appliance Testing for Energy Label Evaluation – Experience with testing 80 cooling appliances from the ATLETE project

Juraj Krivošík, SEVEn, The Energy Efficiency Center, Czech Republic, juraj.krivosik@svn.cz

Therese Kreitz, ADEME – French Environment and Energy Management Agency,

Michal Zakrzewski, CECED – European Committee of Domestic Equipment Manufacturers,

Milena Presutto, ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development,

Stefano Faberi, ISIS - Istituto di Studi per l'Integrazione dei Sistemi, Italy.

Abstract

The "Appliance Testing for Energy Label Evaluation (ATLETE)" project, co-financed by the Intelligent Energy Europe Programme, was launched in June 2009. It comes to a conclusion by the end of May 2011. The project is designed to increase the EU-wide implementation and control of energy labelling (and eco-design) implementing measures for products. The project directly tested 80 randomly selected refrigerating appliances. The followed test procedure was fully in line with the two-step provisions of the energy labelling directives 9472/EC and 2003/66/EC. The results show that 84 % of appliances subjected to testing, for which testing has been concluded complied with the energy efficiency class declaration and the two related key parameters: energy consumption and storage volume. However, when all five tested parameters are taken into account, including storage temperature (and the climate class), freezing capacity and temperature rise time, the compliance falls down to 47 %. The results indicate that level of compliance is low and European-wide market surveillance activities are essential.

Introduction to the ATLETE project

The project "Appliance Testing for Energy Label Evaluation (ATLETE)", co-financed by the Intelligent Energy Europe Programme, was launched in June 2009. The project includes five partners: ISIS (Italy) project coordinator, ADEME (France), CECED (Belgium), ENEA (Italy) and SEVEn (Czech Republic). It is designed to ensure that the EU energy labelling scheme – but also the eco-design Regulations related to appliances – is more effectively implemented through exercising a wide-scale market control action for refrigerating appliances developed throughout the entire EU. The main steps undertaken are:

- Review and a comparison of the national legislations related to energy labelling, methodologies and results achieved in the conformity assessment;
- Setting of a verification of the manufacturers declarations, fully in line with the two-step provisions of the Energy labelling directives 9472/EC and 2003/66/EC, a methodology for laboratories accreditation and appliance models selection;
- Achievement of the first pan-EU testing results on a large household appliances, namely refrigerators and freezers;
- A wide set of dissemination actions, aimed at increasing the attention of the National Authorities on the energy labelling scheme through a better awareness of its impact of the national energy efficiency;

- The definition of guidance to EU and National Authorities for increasing effective labelling implementation.

The project, to be completed by end May 2011, is organised in seven thematic Work Packages (Figure 1), which also outline the structure of the present paper.

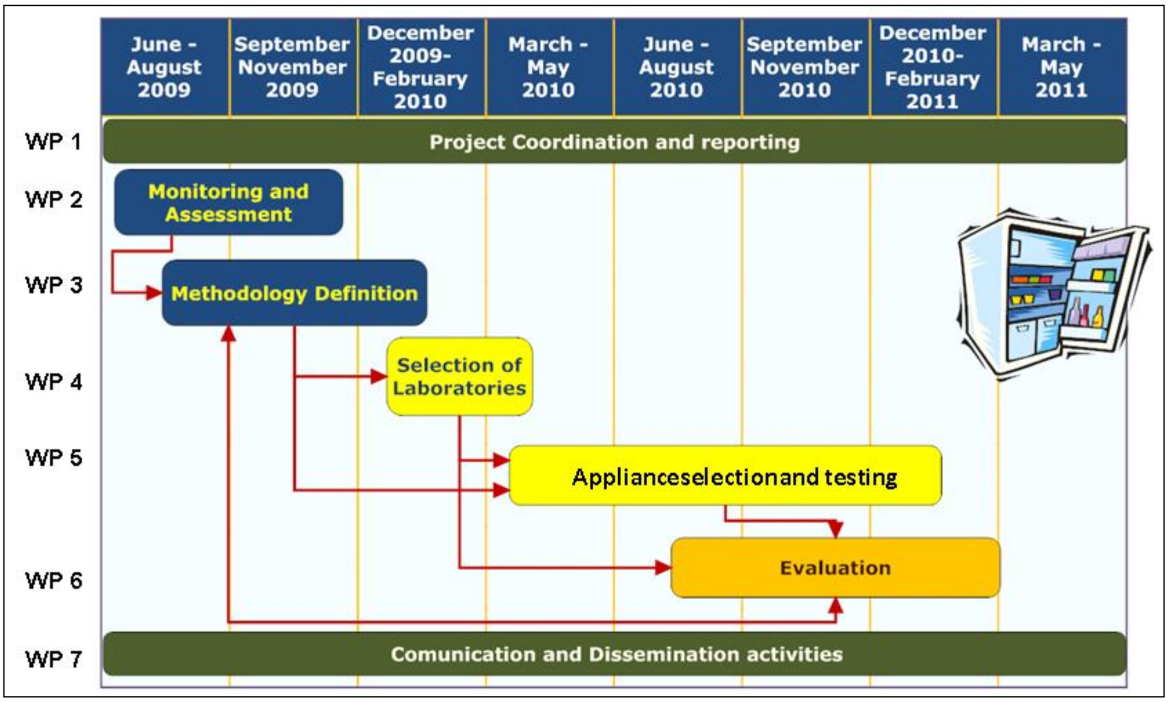


Figure 1: Organisation and timing of ATLETE project activities.

The activity of the project Consortium is supported by an International Advisory Committee including major stakeholders involved in the verification and compliance actions to eco-design and labelling of products: retailers and consumer associations, governmental organisations, energy agencies and NGOs, and in charge of an overall quality control of the developed actions and procedures and in facilitating the dissemination of the testing results.

European legislation related to energy labelling

The introductory part of the project included a review and a comparison of the national legislations related to energy labelling of household appliances and a review and a comparison of the methodology and results of the conformity assessment. A detailed questionnaire was prepared, including the following aspects:

– Transposition of the EU labelling and eco-design legislation into national legislation,

– Legislation on laboratory testing,

– Legislation on testing institutions,

– Legislation on sanctions,

– Legislation on information sharing,

  - Distribution of the energy labels to shops,
  - Organisation of the surveillance shop visits,
  - Compliance rates and sanctions

The type of legislation selected for transposition of the EU labelling and eco-design directives is summarised in Figure 2.

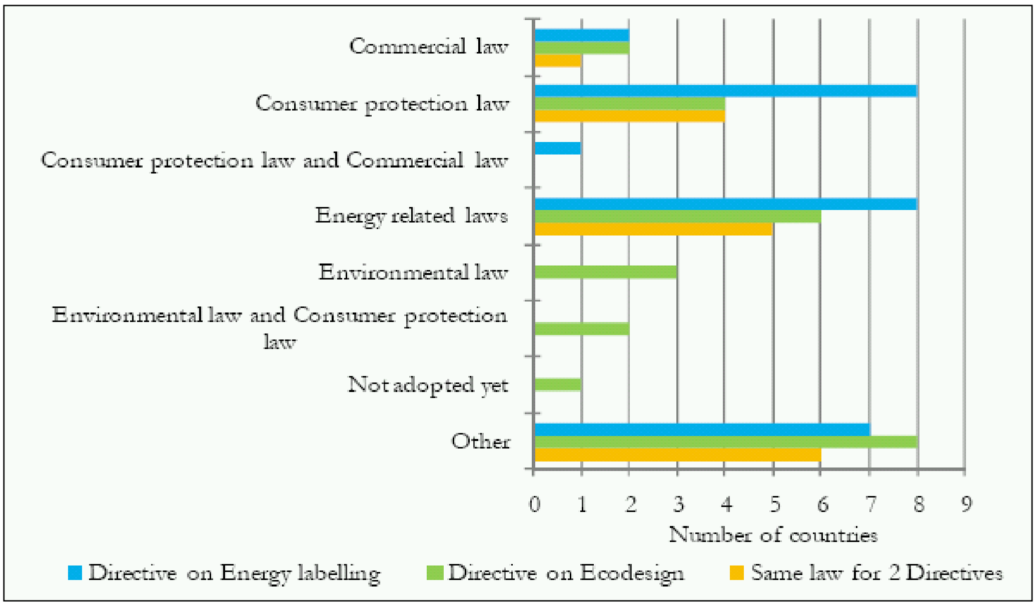


Figure 2: Type of legislation chosen to transpose the EU labelling and eco-design directives

The full report about legislation of the EU Member States on the energy labelling can be downloaded from the project website [1][1]. At a general level, difficulties related to the European regulations' content have been pointed out following the interviews with Member States [2]:

For instance, the interviews revealed the fact that the energy efficiency classes on the labels are sometimes too narrow to cope with. When this is combined with the important tolerance margins allowed when measuring the energy consumption, some appliances can artificially be classified in a better class then they should be. This is not very good to build trust in the energy label as a whole.

Another example is the lack of procedural details of the surveillance measures in the European legislation and of the specific actions to be undertaken. Even though this was justified by the respect of the subsidiarity principle, it has led to a disparity of the resources and methodologies used by Member States. As consequence, energy labelling conformity assessment has never been considered as an imperative topic in most of the EU Member States.

An improvement on these matters can only come from the revision of the framework Directive on Energy Labelling (adding for example provisions on actions to be undertaken for market surveillance, a European coordination of information exchange between Member States, a new form of the label etc.) and the product specific Regulations implementing the Eco-design framework Directive (defining tolerance margins, the algorithms to calculate the energy efficiency to better reflect consumer use, etc.).

Difficulties related to the coordination between market surveillance Authorities on one hand, and State institutions responsible for EU Directives' transposition on the other hand, were also noticed during the survey. In a few countries, enforcement Authorities could not be contacted despite several attempts and no information about market surveillance activities was available.

An additional recommendation can be to further assess the efficiency of current institutional frameworks in these countries, as indicated in Article 18 *Obligations of the Member States as regards organisation* of Regulation 765/2008: "Member States shall periodically review and assess the

[1] This report also contains a summary of the activities of individual European countries in terms of distribution of the energy labels to shops, compliance shop visits, organisation of formal product tests. The report includes also the "Recommendations for an EU conformity assessment methodology".

functioning of their surveillance activities. Such reviews shall be carried out at least every fourth year and the results thereof shall be communicated to the other Member States and the Commission and be made available to the public, by way of electronic communication and, where appropriate, by other means”.

Selection of Laboratories

Selection of laboratories was conducted according to the project procedure and a Call for Tender was issued and organised covering laboratories known to be accredited to conduct energy label verification test of refrigerating appliances.

The identified selection criteria, including the knock-out ones, are as follows:

1. General Requirements

- Laboratory status (is the laboratory independent, owned by a manufacturer or by another involved stakeholder?)
- Ability to test the <*appliance types*> (for this project: built-in and free standing refrigerating appliances, compression type only)
- Ability to report in <*in the requested language*> (for this project: English) Accreditation for testing domestic refrigerators and freezers (EN 17025 and other ISO/EN standards)
- Capability to fully follow a given test method (without in-house interpretation of test conditions)
- Is the laboratory ready to accept a visit of an ATLETE expert and of the representative of the manufacturer(s) of the tested unit(s)?
- Is the laboratory capable to search for, manage to collect and purchase on the EU market the appliance models (from 1 to 4 units) assigned for testing?

2. Laboratory experience

- Testing experience: involvement in standardisation activities, experience in previous Round Robin Tests/Performing tests, appliance types and relevant models tested over the past 5 years according to ISO-IEC/EN standards
- Staff experience: including education and (periodic) training of technicians who will perform the tests, is re-training foreseen when new Editions of the standards are published?
- References (e.g. from companies that undergo testing in the laboratory).

3. Testing capability

- Testing capacity (type of appliances and models for each type that can be tested in parallel) (a minimum capability will be requested for the project)
- Testing timing (within certain defined time frame)[2].

4. Available equipment for testing

- Type of equipment used, including reference machine(s) (not for the ATLETE project)
- Accuracy of equipment, including meters
- Regular supply (if necessary) of the consumables (i.e. M-packs for refrigerating appliances. Standard detergent, test load, etc. when other appliances are tested)
- Calibration frequency, if any

---

[2] One of the knock out criteria is the time needed to perform a test, i.e. the capability to run the given number of tests in the project time-frame. In theory this could have led to rejecting highly qualified Laboratories just for timing constraints. It was not the case with this project, but in the final Recommendations of the project all aspects concerning laboratories selection will be clearly stated in order to avoid any negative effect on Laboratories reputation.

- Control of the supply voltage stability.

5. **Testing details**
    - Capability to test all testing requirements (for this project: energy consumption, storage temperature, storage volume, freezing capacity)
    - Maintenance and control of consumables (stability of dimensions and mass of the test materials if appropriate, management of test load)
    - Test room(s): number of test chambers; number of appliances that can be tested in each chamber
    - Test room conditions: control of the humidity range, temperature range, air speed, temperature gradient.

6. **Reporting and documentation**
    - Method for confirming validity of tests
    - How and how frequently ambient conditions and parameters under test (ambient temperature, energy consumption, energy, voltage and time) are recorded.
    - Are templates followed for the reporting of standard tests (i.e. tests run according to EN standards and EU legislation); are the templates available for examination?

23 laboratories were initially identified all over Europe and then contacted in late December 2009, with the invitation to participate to the project starting with the compilation of a Questionnaire on laboratory technical and performance characteristics and testing experience. Eventually, 15 laboratories replied with full answers to the questionnaire. All replies were assessed against a scoring system and laboratories capability to perform the needed appliance testing in the foreseen timeframe. As outcome, a group of 10 potential candidate laboratories was identified.

The 10 potential laboratories were contacted again through a Call for Tender, focused on testing time and cost aspects of the testing procedure. The following selection criteria were highlighted in the call for tender:

- Questionnaire score: the score achieved by each Laboratory on the Questionnaire will weight 70% of the final result, complemented by possible direct visits of the ATLETE project experts to the Laboratory;
- Offer score: 30% of the final result will come from the pricing offer. Offers exceeding 2.500,00 Euro per appliance model were discarded;
- Test Timing: timing for the test completion is considered a knock-out criterion, but no additional score has been given to Laboratories declaring to be able to provide testing results before the deadline.

As a consequence, five laboratories were shortlisted. A final quality control was assured by a direct visit of Laboratories by a technical expert from CECED. Four laboratories were finally selected[3]:

- Re/genT BV (The Netherlands),
- ipi-Institut für Produktforschung und Information GmbH (Germany),
- LCOE - Laboratorio Central Oficial de Electrotecnia (Spain), and
- VDE Prüf- und Zertifizierungsinstitut GmbH (Germany).

Several meetings have been organized with the testing laboratories before and during the testing procedure in order to iron out any possible question marks relating to the interpretation of the harmonised standard (test method) and to ensure that the testing procedure in all four laboratories

[3] The full list of invited laboratories, questionnaire submitted, and its evaluation can be seen at [3].

runs in completely the same way. The meetings also provided opportunity for feedback and exchange of experiences relating to the testing phase.

Appliance testing

Preparations for appliance testing started in April 2010. The market research firm GfK delivered initial data on the EU market of refrigerators and freezers at the beginning of 2010, in order to support the definition of the sampling methodology.

Geographical and technical scope of tested appliances

The geographical scope of the targeted appliances is:

- EU27 Member States as far as possible. If external market statistical sources have a more limited scope, it should be evaluated that the limitation of the source does not exclude specific markets (e.g. Luxembourg coverage may not be considered an issue if both Belgium and Germany are taken into consideration)
- National best selling products in the following countries: BE, DE, DK, ES, FR, IT, NL, PL, UK.

The technical scope of the targeted appliances in all refrigerating appliances (refrigerators and freezers), divided into four categories:

- Bottom-mounted refrigerator-freezers (i.e. with freezer at the bottom) also known as “combi” refrigerator-freezers
- Top-mounted refrigerator-freezers (i.e. with freezer on top of the appliance);
- Freezers, upright and chest together;
- all other refrigerating appliances (mainly simple refrigerator, but also side-by-side refrigerator-freezers).

Methodology and criteria for the models selection

The definition of the methodology and criteria for the selection of the models to be tested is based on automatic and fully transparent procedures, ensuring that the tested appliances respond to the defined criteria. Two approaches are followed worldwide:

1) “random selection” of the models, selected randomly in a quantity to be representative of the (national or EU) market
2) “maximum failure selection”: the selection of the models is done on the basis of personal criteria in order to pick-up the models suspected to be non-compliant (a higher probability of non-compliance).

The outcome of these two approaches is different. For the “*random selection*” the resulting ‘failure rate’ (or the complementary ‘compliance rate’) gives a picture of the investigated market within a certain time frame, but the resources to be used are considerable. For the “*maximum failure selection*” the outcome is not representative of the market situation, but of the use of the available resources is lower.

When preparing the ATLETE project, the project consortium thoroughly discussed this issue and the conclusion was that for the first round of a pan-EU compliance assessment a “random selection” would be appropriate, since for the first time an EU market picture will be derived. The alternative approach could be used in future rounds of the assessment, to verify specific products and models after having already clarified the overall market situation. In the end a “semi-random selection” approach based on best seller was outlined.

The ATLETE project appliance models selection

The ATLETE project undertook the testing of 80 models of refrigerators and freezers divided into two groups pursuing the following criteria:

- the first group (40 appliances) includes the “EU bestsellers”, namely the best sold models in the EU27;
- the second group (40 appliances) includes models randomly selected within the remaining producers active on the EU27 market.

The selection of the models and the testing of the two groups started in parallel, considering the capacity of the laboratories, thus avoiding the need to choose whether the testing should start with the small or the large manufacturers (as far as market share in the European market is concerned).

At the end of March 2010 the market research firm GfK delivered the sales data of refrigerators and freezers in January 2010 and, at beginning of April 2010, 80 models were randomly selected (Table 1).

Table 1 Criteria for appliance models selection

Producers market share	Total number of producers	of which EU		of which national		Selection criteria			Models for random selection	Selected models	Models per manufact.	Market share coverage	
		Total	of which a list of models can be provided	Total	of which a list of models can be provided	Appliance categories	Best seller models	Random selection per manufacturer				All producers	Producers whose data are available from GfK
>= 10	**4**	**4**	**4**	**0**	**0**	4	15	-	240	16	4	48	48,0
>=5 <10%	**3**	**3**	**3**	**0**	**0**	4	15	-	180	9	3	12	12,0
>=1 <5	**9**	**9**	**6**	**0**	**0**	4	15	-	360	18	3	24	16,0
>=0,5 <1	**12**	**10**	**10**	**-**	**-**	1	10	-	100	20	2	5	4,2
>=0,1 <0,5	**33**			**16**	**4**	1	10	-	40	4	1	10	5,2
		17	**13**	**-**	**-**	1	10	-	130	13	1		
<0,1	~~294~~	~~293~~	~~231~~	~~1~~	~~0~~	~~1~~	~~10~~		~~0~~	~~0~~	~~1~~	1	0,0
total	355								1.050	80		100,0	85,3

As soon as the selection of laboratories was finalised, the selected appliance models were distributed between the laboratories, through a random selection system that took also into consideration the distance between the laboratory and the country(ies) where each model was expected to be sold and the average purchasing price. By doing so, the project consortium tried to limit the logistics costs and ensure that the average unit price between laboratories is more or less similar.

Voluntary Protocol for remedy actions

In March 2010 project partners, as advised by International Advisory Committee, invited representatives of 68 manufacturers (and brands) to sign a Voluntary Protocol for remedy actions – before models for testing were selected. The signatories were given the possibility to take voluntary remedy actions by correcting the label declaration(s) according to the result of the laboratory tests, should subsequent testing for their respective model(s) at the first stage of the procedure suggest suspected non-compliance. In this case the verification test would stop at this stage without going to Step 2 (testing of three additional units of the model). Eventually 27 manufacturers signed the Protocol. This covers 54 (or 67%) of the 80 selected appliance models and 78% of the European market, considering the market share of the signatory companies [4].

All manufacturers were also invited to submit the list of countries, where the selected models have been distributed.

Appliance testing

The parameters to be tested for each model are those requested by the EU energy labelling directives 94/2/EC and 2003/66/EC are presented in Table 2.

Table 2 Parameters tested within the ATLETE project with the relevant tolerances

Parameters	Unit	Tolerance
Energy consumption	*kWh/24h*	15%, then 10%
Storage volume	*Litre*	3% or 1 litre
Storage temperature	*°C*	no tolerance
Temperature rise time*	*H*	15%, then 10%
Freezing capacity*	*Kg*	15%, then 10%, and at least equal to the minimum

* for freezers and refrigerator-freezers only

After receiving the lists of assigned models, laboratories started searching for models and making purchases from the market. Some problems were reported for the purchasing of few models, especially belonging to small manufacturers with a minor market share. In this case, either an equivalent model was indicated to the laboratory or the random selection of the appliance to be tested was repeated. Laboratories directly contacted the manufacturers of the selected models asking for the product fiches and loading plans to start the testing phase. There were some difficulties reported with obtaining proper data.

The proposed verification procedure

The testing was conducted fully in accordance with the two-step procedure described in the former energy labelling (94/2/EC and 2003/66/EC) and minimum efficiency requirements (96/57/EC) directives but also in the more recent eco-design Regulation 2009/643/EC [5] and delegated Regulation 2010/1060/EU [6], and based on the requirements of the harmonized standard EN 153 and reference in ISO/IEC standards[4].

The procedure has been better specified and improved taking into consideration the experience gathered in the main markets worldwide. In particular:

- Step 1: one unit of each selected model is initially tested. If the model in question complies with all the labelling declarations[5] the model is deemed to have positively passed (including the relevant tolerance) and the procedure ends. In case the unit fails to comply with any of the labelling declarations for the specific product, Step 2 follows.
- Step 2: in this step three other units of the same model are (randomly) selected from the market and tested. If the average of the three units (including the relevant tolerance) complies with the declared values, then the model is deemed to comply; if not, the model fails.
- Between the two Steps, it was considered appropriate to include an additional phase:
  - Contact the relevant manufacturer, to be informed about suspected non-compliance (Step 1 results of the unit failing the test) and asking for checks of possible declaration mistakes. At this stage the manufacturer may choose to accept a non-compliance of the appliance model on the basis of the Step 1 test result and to correct the energy labelling declaration accordingly, or alternatively may choose the option of proceeding to Step 2.
  - The manufacturer has the right to check in situ (under supervision of the test laboratory) if the tested unit is not damaged (perhaps during the transport). The testing laboratory

[4] EN 153 and ISO 15502:2006
[5] Compliance with the minimum efficiency requirements in Directive 96/57/EC is taken for granted nowadays.

should be required to check each sample to ensure that it has no obvious operating defects, for example due to an accident.

- Manufacturer who believes that the tested unit is defective should be able to inspect the unit in situ (under supervision of the test laboratory) and report on the findings to the project leader. In this case, the onus would be on the manufacturer to provide evidence that a production defect capable of affecting the test results does exist; furthermore he would need to demonstrate that the "defect" is peculiar to the test unit alone and not common to other samples of the stock of the appliance.
- If the evidence is provided and accepted that the tested unit is defective or damaged, the Step 1 test would be cancelled and a new test will be undertaken in the same laboratory either on the original unit with repairs or on a randomly selected second sample of the stock. The costs associated with inspection and re-testing of defective/damaged samples should be borne by the manufacturer or by the market surveillance Authority (this last point under discussion for future recommendations).

To improve the knowledge and the confidence on the testing procedure, it was also considered appropriate that during Step 1 and/or Step 2, the partners of the ATLETE project or a representative of the manufacturer of the model under test could have the possibility to assist to the test (under supervision of the test laboratory). However, no partial results could be disclosed. In case of dissent with the testing conditions followed in the laboratory the manufacturer/project partner would report back to the project leader (later to the market surveillance Authority) before the result of the Step is known.

Non-compliant cases - only after the second Step of the procedure or after Step 1 should the manufacturer accept the non-compliance - would be disclosed by the project leader to the manufacturer and the EU Market Surveillance Authorities of the countries where the specific model was expected to be sold. Legal actions for non-compliance after the second Step of the procedure will be then left to the EU market surveillance Authorities, while if the manufacturer accepts the non-compliance result after Step 1 and modifies the energy labelling declaration accordingly no further actions will be asked for to the national Market Surveillance Authorities

Cost of the verification procedure:

For ATLETE the costs of the verification exercise were paid by the project budget. However, in view of the further use of the defined procedure at EU level, an arrangement for the coverage of the costs is proposed for discussion:

- Step 1 costs are to be met by the Market Surveillance Authorities;
- where the manufacturer decides to undertake Step 2 (after a negative results of Step 1), it is liable for all related costs of Step 2, irrespective of the outcome (this aspect needs to be further clarified because it is strictly related to the reliability of the testing laboratory, i.e. the accreditation or a similar control action on the laboratory);
- where the unit selected for testing is demonstrated to be defective in manufacture, the manufacturer is liable for all resulting additional costs incurred for testing (new Step 1 and Step 2);
- where a unit selected for testing is demonstrated to be damaged, the Market Surveillance Authority is liable for all resulting additional costs incurred for re-testing the unit in Step 1, the manufacturer will be liable for all resulting additional costs incurred for the further Step 2.

Disposal of the tested appliances

At the end of the ATLETE project all tested appliances (excluding those defective/damaged, if any) were donated to selected charities located around the laboratories. Appliances with measured energy consumption below the eco-design requirements have been recycled. This final disposal of the tested units was agreed with EACI during the negotiation of the ATLETE project. Outside the project, all tested appliances belong either to the testing laboratories or the Member States Market Surveillance Authorities, depending on who has actually paid for the purchasing.

Results

Appliance testing started at the end of June 2010. The Step 1 of the verification procedure for the 80 models was concluded in February 2011. The whole testing exercise was finalised at the end of March 2011.

In total, tests of 58 models have been completed. Further 13 models are pending in the time of finalizing of the paper (April 2011)[6]. For 11 models, the test could not be completed because 3 additional models for Step 2 have not been found on the market.

From the 58 models for which the test has been completed, 84% of appliances subjected to testing and for which testing has been concluded complied with the energy efficiency class declaration and energy consumption. For storage volume, the level of compliance declines to 76 %. The level of compliance in parameters, which have rarely been tested in the past, such as freezing capacity, is even lower – 74 %. When all tested parameters are taken into consideration, the rate of compliance declines to 47% (Figure 3).

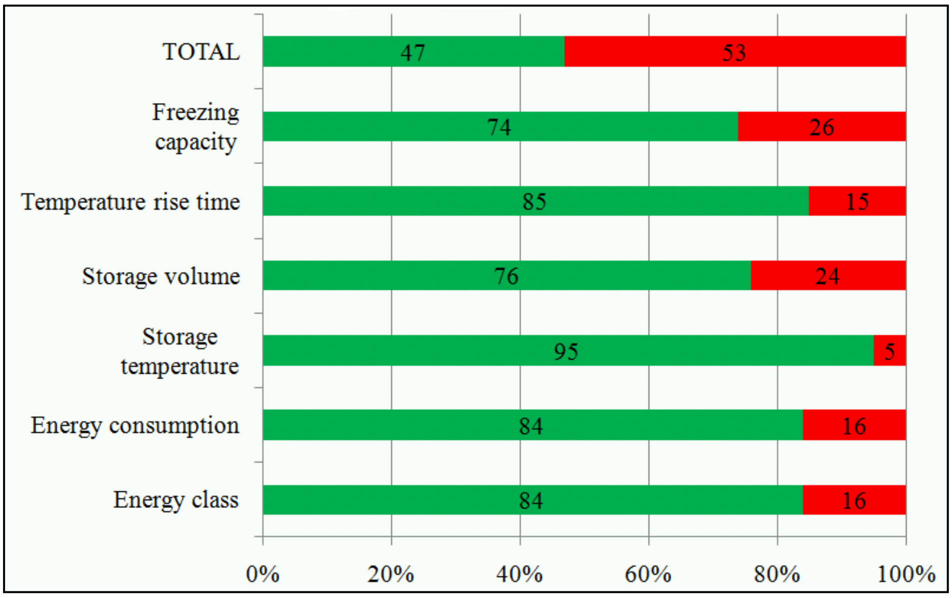


Figure 3 Results of the tests. Note: Green (left) = Pass, Red (right) = Fail

Looking closer at the results of energy class declaration, 84 % have correct energy class declaration. 7 of the 58 tested models (13%) were overrated by 1 class and 2 tested models (3%) were overrated by 2 or more energy classes (Figure 4).

[6] The final results for 13 appliances have been delayed due to logistical reasons related to fulfilling the testing procedure only. The slight delay in the publication of some test results should not be considered as an indication of suspected non-compliance of the appliances concerned.

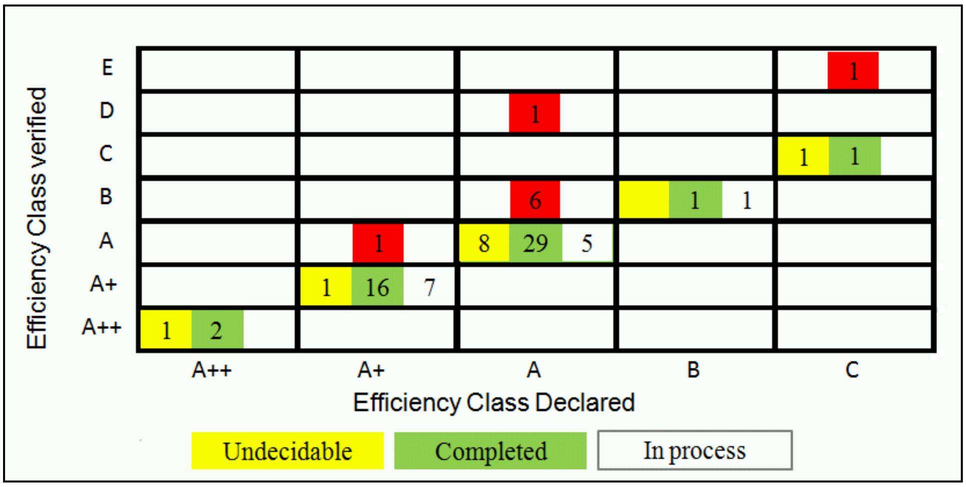


Figure 4 Energy class declared and verified

The results of energy consumption test (Figure 5) indicate the differences between declared and verified energy consumption of the models. The tolerance for Step 1 is 15%, tolerance for Step 2 is 10 %. Interestingly, the tests revealed that for some models, the verified values were actually better by more than 15% (meaning the energy consumption was lower) than the declared values.

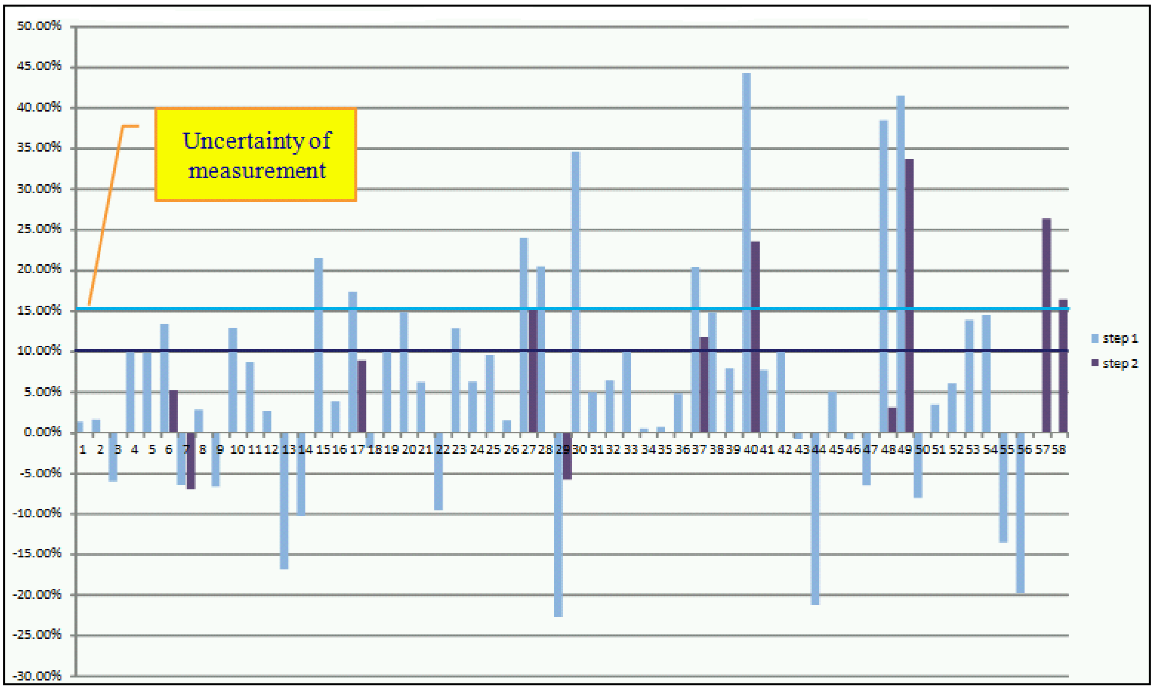


Figure 5 Energy consumption results for Step 1 and Step 2

Some of the manufacturers who signed the voluntary agreement took remedy actions after Step 1 without resorting to Step 2 procedure. Among other, the remedy actions entailed changing the plates in technical fiche or catalogues. Full list of results for individual models together with the remedy actions is available at the project website [7].

Conclusions and next steps

In total, 80 refrigerators and freezers and refrigerators/freezers were tested strictly as to the formal procedures. The test procedures including the selection of models and selection of testing laboratories have been developed and are available for further use. The main conclusions as to development and implementation of the testing procedures are:

- There is need for higher specificity in the definition of manufacturers/traders responsibilities.

- The tolerance margins may need to be reduced.
- There is a clear need for establishment of an EU database to store and search the information about controls and tests for electrical appliances.
- The comparison of tests' results among enforcement authorities (not only Ministries) could be organized and supported by the European Commission.
- Harmonization of model names of appliances which are otherwise the same across the EU would be helpful.

Further conclusions pertaining to the test results are:

- European-wide market surveillance activities are essential, practically possible and affordable.
- Test results suggest that a stronger level of market surveillance is vital to ensure a higher level of product compliance.
- Market attention brings better results. Compliance of data on energy label is better than compliance of data on fiche.
- Speed of procedures must be compatible with market speed. Market fragmentation/seasonality is even higher for other products than refrigerators and freezers.

Analysis of the transferability of the established methodology to other types of products

As a next step, the transferability of the methodology to other products under energy label will be examined. Furthermore, the availability of laboratories in the EU capable of performing testing on the products with sufficient capacity is a crucial element. A thorough analysis and comparison of the on-the-shelf lifetime of products and the necessary laboratories' testing time will demonstrate whether the methodology is sufficiently quick and flexible for all products.

References

[1] Kreitz, T. et al. *Report on the national legislations regarding energy labeling*, ATLETE project. 2010. Available at http://www.atlete.eu/index.php?option=com_docman&Itemid=111 (April 2011)

[2] Kreitz, T. et al. *Recommendations for an EU conformity*, ATLETE project. 2010. Available at http://www.atlete.eu/index.php?option=com_docman&Itemid=111 (April 2011)

[3] Presuto, M. and Zakrzewski, M. *Guidelines for EU testing of Energy Using Products*. 2010. Available at http://www.atlete.eu/index.php?option=com_docman&Itemid=111 (April 2011)

[4] Atlete, *List of manufacturers that signed the voluntary protocol for remedy actions in Atlete - Status on the 24/06/2010*. 2010. Available at http://www.atlete.eu/index.php?option=com_content&view=article&id=113:list-of-manufacturers-that-have-signed-the-voluntary-protocol-for-remedy-actions&catid=41:top-headlines (April 2011)

[5] European Communities. Regulation 2009/643/EC of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigerating appliance.

[6] European Communities. Delegated Regulation 2010/1060/EU of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of household refrigerating appliances.

[7] Atlete. *Complete Test Results*, 2011, Available at http://www.atlete.eu/index.php?option=com_content&view=article&id=125&Itemid=117 (April 2011)

The ATLETE project has been co-financed by the Intelligent Energy Europe programme.

Graphical language for identification of control strategies allowing Demand Response

David DA SILVA, Bruno DUPLESSIS and Jerome ADNOT
Center for Energy and Processes – MinesParistech

Abstract

Due to new innovations in communication systems, electrical appliances are now capable of participating actively in smart grids control management.

Each appliance has already several controls incorporated. In order to determine the best way to control an appliance in a smart grid context, we present a methodology based on a graphical language, which makes possible an easy identification of the available control strategies and will be used for future developments in terms of smart controls.

The Language is divided into two different levels of complexity with different results.

First level: Based on an empirical description of the controls available to the user, a first graphical representation of the appliance operation can be produced. This will allow the identification of the electric appliance availability for demand response control strategies based on the appliance existing controllers.

Second level: This level requires detailed information and/or measurements of the appliance operation, so that more complex control strategies can be deduced. Due to the more complex operation description some of the deduced strategies, for this second level, could need adding new controls to allow their correct application. However it is up to the user of the language to choose the degree of the description complexity.

This second level allows the user to know which components are the more energy and power demanding and how they are controlled, meaning that more accurate strategies can deducted.

Manufacturers and power utilities can then identify their control strategies to be implemented in terms of demand response for electrical appliances.

Introduction

An important part of electrical equipments flexibility analysis is related to their aptitudes for possible remote control and/or operation modification. The control of electrical equipments will depend in large part where the controls or operation modification can be made.

To be able to detect and analyze the possible operation controls, it was created a graphic language which represents, in a methodical and simplified form the electrical appliances operation and it reveals the operating processes called “non-visible” (to the user) of equipment operation. Thus allow to understand the various operating processes of the equipments and their load diagram. This language enables to condense all the information of an equipment operation into graphic.

As a result, this language makes it possible to find in a simplified and precise approach, the existing control strategies but also to find possible equipment modifications, in order to make them more attractive for the intelligent control.

The existing languages were created for product development, automation of processes or equipments, software and other. In our case, we do not want to describe the appliances operation with this purpose; the goal of the language is only to highlight the control options in a simplified, fast and intuitive form.

In the following sections it will be presented and defined the suggested language specifications.

Description of the graphical language for Identification of load control availability (ILCA)

The definitions and descriptions of the various elements which constitute the language are described hereafter:

State: it defines the operating condition, like an appliance operation process with a precise objective.


: This symbol represents an operating state of the appliance. The power demand can be static or dynamic (ex: power modulation). A state can also contain sub-states. Sub-State is an object in a stage where one or more operations can be carried out. (Example: state washing of a washing machine – Figure 3)

Transition: the transitions are the elements responsible for the passage for a state towards the other. They can be simple Boolean transitions to more complex transitions including equations or logical functions.


: This symbol represents one transition. It displays the event which must occur to have a transition from one state towards other. There are of several types transitions: a contact ON/OFF, a logical test, introduction of the value of a variable or other.

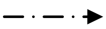
Connection: elements with one or two directions, they make the connection between states and transitions or between transitions.

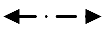

: This symbol represents a connection with the user intervention and it can occur only in one direction;

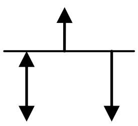

: This symbol represents a connection with the user intervention and it can occur in both directions;


: This symbol represents an automatic connection (internal control of the appliance) only in one direction;

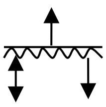

: This symbol represents an automatic connection (internal control of the appliance) in the two directions;


: This symbol represents a connection from/with a communication network (ex: grid price signals…), where the information can be transmitted only in one direction.


: This symbol represents a connection from/with a communication network (ex: grid price signals…), where the information can be transmitted in both directions.


: This connection represents a logical disjunction “or”, i.e. the appliance operation is divided into two or more pathways and then the first to be activated (by a transition) will determine the next appliance pathway.

The arrows show, if the transition can be made in the two directions (marks with arrows on the left) or only in one direction (marks with arrows on the right).


: This connection allows that two or more transitions are carried out starting from a single state or transition. This connection can also be used to converge stages or transitions.

The arrows show if the transition can be made in the two directions (marks with arrows in bottom on the left) or only in one direction (marks with arrows in bottom on the right).

-----► : Connection of an external variable (example: external temperature, thermal loads of the building)

External Parameters: This object specifies the external parameters to the system in analysis, which will have a direct role in the machine operation (ex: Temperature of water, temperature of air, etc).

 : This symbol represents the external or variable variables controlled by the user

Possible Control points: the objective of these elements is to indicate the parameters which have an impact on the operation of the machine in analysis, so that strategies can be identified afterwards.

 : indicate the places where a control can be implemented

Operating States

Several studies [1,2] have identified the principals operating states of electrical equipments. Next we present most important operating states and their definitions.

Off - The equipment remains connected to the power source but it does not produce any function and it does not transmit or receives any information. The equipment expects a physical intervention of the user (through an ON/OFF button for example).

In this mode the appliance can consume, however a modest amount of energy.

Passive Standby - In this state the equipment is put into low power mode by a certain means like switch or remote control ("sleeping mode", if remote control or internal sensor or timer). The principal function of the appliance is not carried out in this state.

"*Passive Standby"* can normally understand the following functions:

- Reactivation by remote control ("remote control", it should not be confused with *Network Standby*[1])
- Continuous functions:
    - Information or screens with the description of the state of the equipment or clock
    - Sensor of safety
    - Internal Sensor or programmer

Delay Start - the appliance can be programmed to begin functioning at a later time; in some cases up to 24 hours later.

Activate Standby - When the appliance is "ON" but it does not exert his main function (example: when a thermostat stops the electric resistance). This state is normally presented during one of the following cases:

- When a mechanical function is not active (DVD *drive* or engine) but the circuit is energized.
- When the appliance has a battery and it is charging

[1] -Network Standby : In this mode the appliance provides one of the following additional functions (not a main function):

- Reactivation via network command
- Network integrity communication

- When the appliance is in a quiet state (example: amplifier is ON but no audio sound

ON - the appliance executes its principal function

Application method of the ILCA language

The language can be divided into two analysis levels: *User Level* and *Manufacture Level.* Even so, the degree of detail for each of the presented analysis levels is left to the user, who applies this language, according to his objectives.

Level user - the first level is based on the instruction manuals of the equipment and on the empirical experiment of the regulation/control of the equipment.

This level aims to establish appliance control opportunities without the need of additional equipment and/or modifications on the equipment components.

In this case the language describes the operation of the equipment based on the available controls to the user or based on existing external connections.

Level manufacturer - *the* objective of this level is to identify advanced control strategies.

This level of description is directed towards the manufacturers because the new identified strategies, in this level, normally need the addition of the additional regulators, or the appliance components modification.

The manufacturer level is based on technical documents and/or measurements in order to understand the operating/regulation rules of the equipment in analysis, and taking into account the designers expertise. The appliance graphical representation is created by taking into account all its operating conditions and the rules of order intervening in the transition processes between the various states.

Application of the ILCA language to a washing machine

In this chapter we exemplify the application of language ILCA for the case of a washing machine.

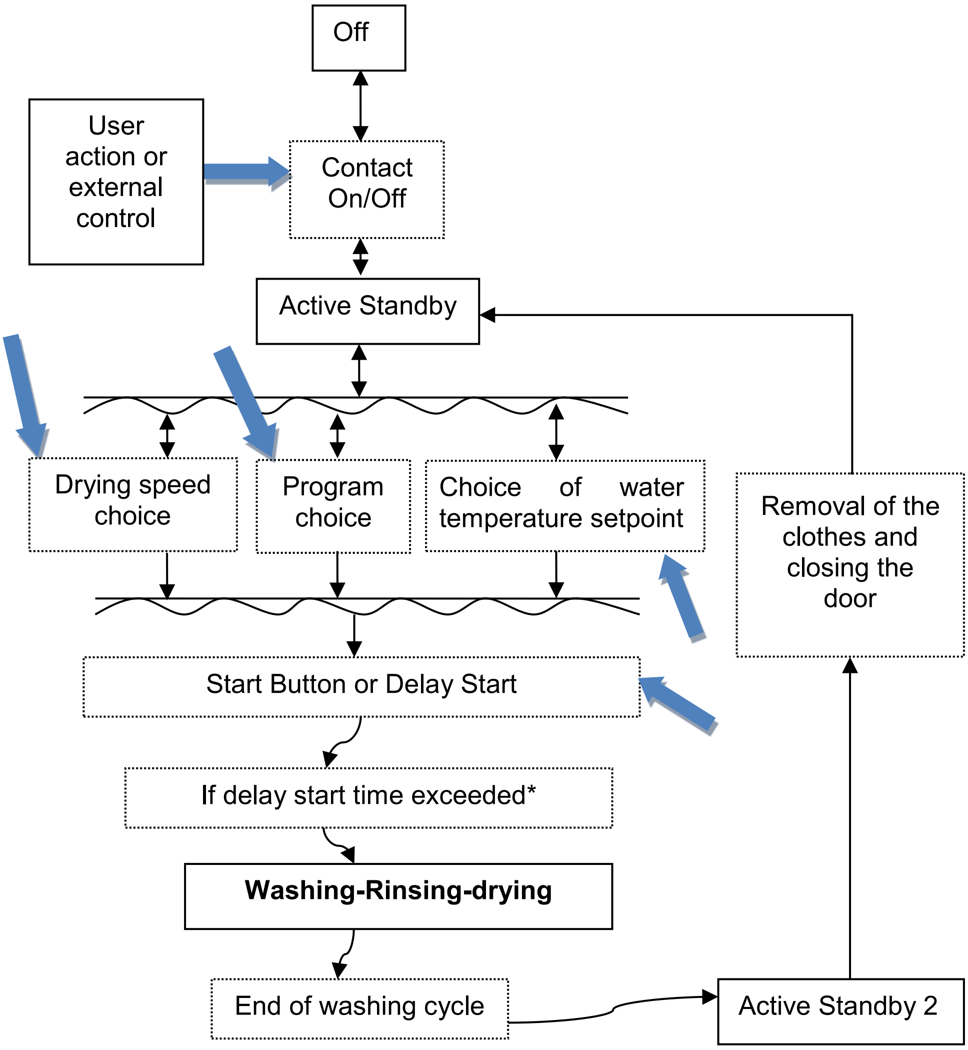
User level analysis of a washing machine

In this analysis we will try to determine the operating states, taking into account the controls available to the user without considering the internal operation cycle of the washing machine.

Table 1 - Operating states of a washing machine - user analysis level

Operating States
Off - the appliance is turned off but it can still be connection to the mains (Possible energy consumption) **Activate Standby** - the appliance is ON but it does not perform his principal function. He expects an action of the user to start the washing cycle. **Washing-Rinsing-drying** – includes several stages: washing, rinsing and drying **Activate Standby 2** - State where the appliance expects an action of the user to empty the machine. In this mode some blink lights and an audio signal can be activated.

The graphic of a washing machine user level is shown in Figure 1.



*-if Delay start available

Figure 1-Graphic of the user level

From the user level analysis, the following control strategies can be deduced:

- *Direct action on the contact ON/OFF* – Washing machine power outage due to high electricity price or due to a direct load program.
- *Choose a different temperature* – Choose a lower washing temperature, which will result in lower energy consumption.
- *Choose a different program* – program with consumes less energy (depends on the appliance model)
- *Delay start* - User information about TOU tariffs (Time Of Use) or other tariffs can be a motor to deferrer the machine operation.
- *To start the machine at low price hours manually* – Same as for delay start, however more difficult to apply since it needs a greater effort by the user

The delay start option has a great value since it allows the user to reschedule his machine operation in a simple and easy way. If we compare the average number of machines with Delay start in Europe (32%) and in France (42%), a difference of 10% can be found [3]. This difference can be explained by the massive diffusion of TOU *(Time of uses)* electricity tariffs in France. This means that electric tariffs diffusion can have an impact over the washing machines preinstalled components, thus allowing their shifting operation.

The mentioned control strategies can be used within the framework of demand side management programs. Programs like ECOWATT Bretagne or ECOWATT Provence-Azur [4,5], which advice consumers shift their electric appliances to off-peak hours, can take the mentioned control strategies as examples.

Nonetheless these strategies can also serve as models to implement controllers enabling the detection of high electric tariffs (smart appliances) and thus changing the machine operation.

Manufacturer level analysis of a washing machine

To be able to carry out the manufacturer analysis, it is necessary to examine technical documents and if possible power measurements to be able to identify the operation cycles.

According to project GEA 1995 and to the EuP 14 [6,3] washing machine operation is based on three stages:

The operation of these appliances is made in a first part by the entry of water and the detergent to humidify the clothes together with a slow drum rotation (during approximately 15 minutes). Then, water is heated by a resistance. The warming-up time will depend on the heater power of the machine (Resistance) and on the chosen temperature by the user. The power of water heater (Resistance) can vary between 1800 W and 2500 W.

When the desired temperature is reached the resistance is turned off and washing remains still a certain time. The “Washing” consists in the detergent action and consecutive rinsings always coupled with the rotary movement of the drum. Sometimes after a certain time the water temperature reaches the below limit fixed by the thermostat (this limit depends on the type of thermostat used) and the water is reheated. Normally the low range and standard machines are equipped with mechanical thermostats ON/OFF with a precision from approximately 5 to 6 °C and the more efficient machines are, normally, equipped with electronic thermostats (PID) which allow a precision of 1°C.

At the end of the washing, the clothes pass through several (3 or 4 generally) rinsings with cool water, where normally at the end of each rinsing the clothes pass for a small drying (rapid rotary movement of the drum). During the last rinsing the softener is applied.

Finished the rinsing phase the clothes pass for a drying phase, where the drum will turn at high speed (400 - 1600 tr/min) and will thus withdraw the water of the clothes.

All this process can be controlled either by an electronic controller or by a mechanical *timer* and it can take between 15 minutes and three hours.

Measurements were carried out to determine if these various states could be identified and to determine the load diagram of a washing machine during a washing program.

According to figure 2, we can distinguish the various operation states of a washing program.

During the phase of washing the resistance will be turned on and once the temperature arrives at the temperature setpoint (Chosen temperature by the user), the resistance is disconnected and thus the power demand is strongly reduced. After washing 4 cycles of rinsing are made, followed by drying.

The nominal power given by the manufacturer was 2000 W, but during a washing program with 30°C temperature setpoint, the 2000 W peak lasted only for approximately 4 minutes. During the rest of the washing program the power remained around 250 W and very different by 2000 W.

The energy used during all the program cycle is due mainly to the water heating, according to the study carried out by Group for Efficient Appliances [6] and by ours measurements, this energy accounts for approximately 80% of the total energy consumed (for a traditional cycle with 60°C). However this percentage is calculated by washing cycle and not by appliance life analysis.

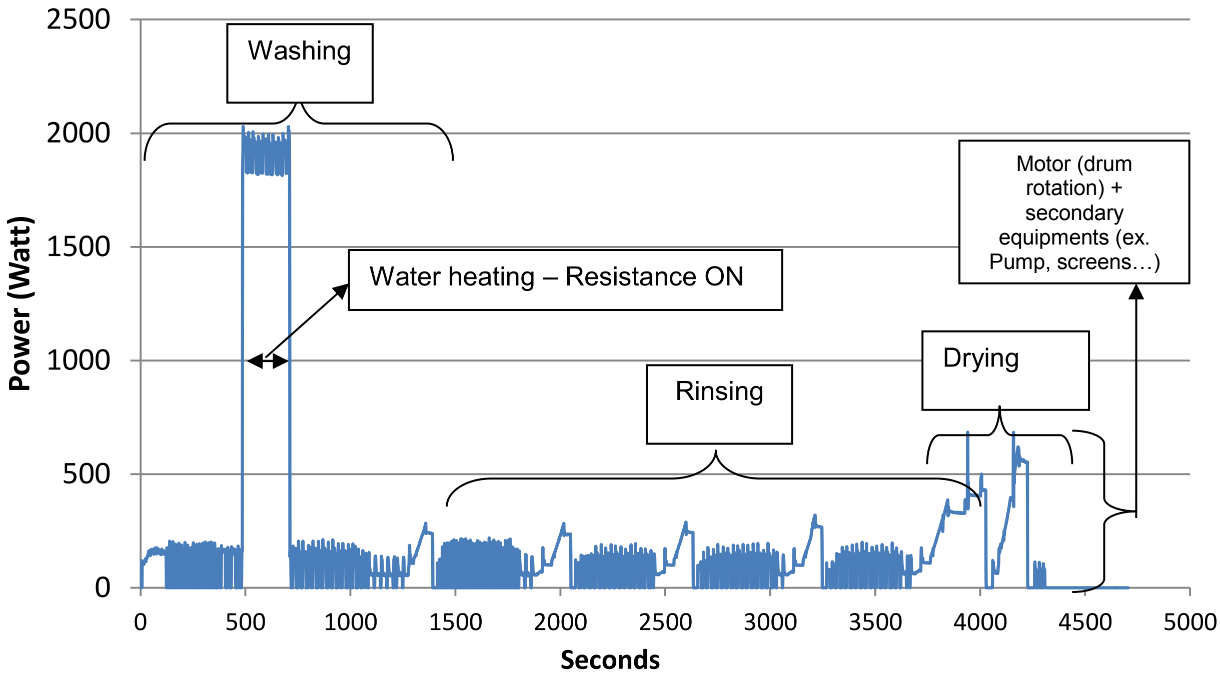


Figure 2- load diagram of a washing machine (cycle with 30°C setpoint)

In order to verify the influence of the low power modes (Off, Active Standby, Delay Start…) when a control is applied, measurements were carried out in shops, in the frame of the SELINA project [2], throughout Europe. The results are present in the Table 2.

Table 2 – Low power modes measurements

Mode	Number of measurements	Average power (Watt)
Off	329	0.34
Delay Start	181	3.14
Active Standby	268	2.31

The single demand power due to low power modes is quite low, less than 0.16 % of the nominal machine nominal power. Therefore the low power modes will have a small influence in load reduction.

Next it is presented the main operating states of a traditional washing cycle for a washing machine.

Table 3 – Operating states of a washing machine - manufacturer analysis level

Operating States
Off - the appliance is turned off but it can still be connected to the mains(Possible energy consumption).
Activate Standby - the appliance is ON but it does not perform his principal function. He expects an action of the user to start the washing cycle.
Delay start – the appliance is On and waiting the signal from the timer to start the washing program.
Washing - continuous rotation of the drum; introduction of the detergent and after approximately 15 minutes (activation of the enzymes), water is heated until water temperature setpoint is reached.
Rinsing - cool water introduction together with the rotary movement of the drum followed by a small drying.
Drying - water draining of the drum followed by a fast rotation (Speed programmed).
Activate Standby 2 - state where the appliance expects an action of the user to empty the machine. In this mode some blink lights and an audio signal can be activated.

The graphic of a washing machine manufacturer level is shown in Figure 3.

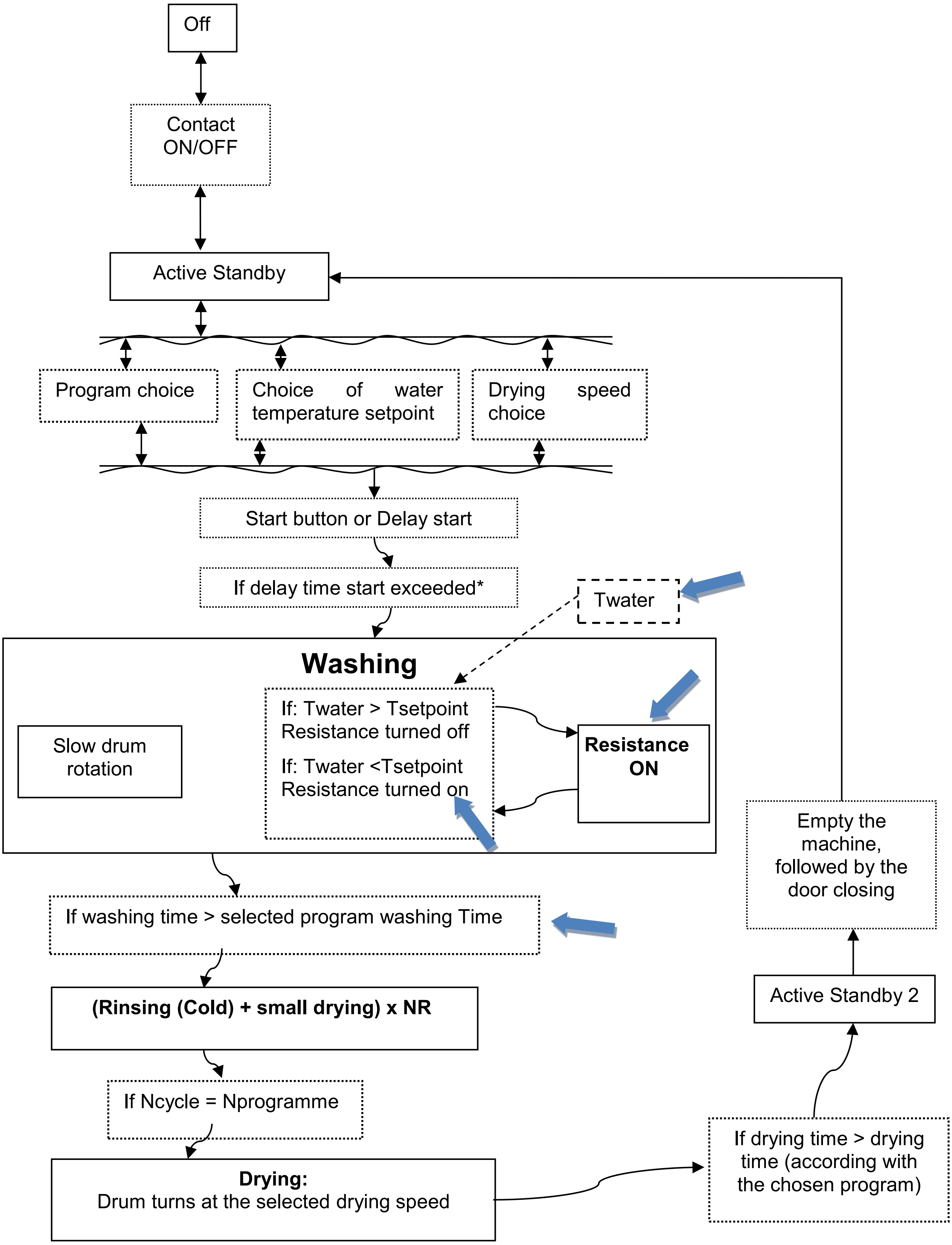


Figure 3 - Graphic of the manufacturer level

Where, Twater, Tsetpoint and NR are the water temperature, water temperature setpoint and the number of rinsing cycles for the selected program

One major power of the ILCA language is that all the gathered information about the appliance operation was condensed into a graphic that is intuitively understandable and easy to interpret.

Detailed description of washing machine operation:

The machine is turned on with contact “ON/OFF”. Then the user selects the temperature, the program and the drying speed. Next the user starts the machine by pressing the Start button.

Once started, the machine will introduce water and the detergent and the drum start to turn slowly. Then resistance is turned on, to heat the water until the water temperature reaches the setpoint. The resistance is responsible by the peak demand, once it is an instantaneous electric water heating system with power ranging between 1800 and 2500 W (see figure 2).

Then when the washing time is exceeded, the rinsing starts. This state consists into drum cool water introduction coupled with the rotary movement of the drum. At the end of each rinsing the clothes pass through a small drying. The number of rinsings will depend on the machine and/or the selected program.

When the rinsing state cycles are finished, the machine passes to the drying state, where the drum will turn at a chosen speed defined by the user (normally ranging between 800 and 1600 rpm).

Finished the drying, the machine passes into a state normally called “Active Standby 2” where the machine expects the that the user unloads the machine and then the user either switch it off or it begins a new washing.

Manufacturers analysis deduced strategies and their discussion

In the ILCA representation all the transitions have a control potential. Though, as it was seen before the responsible element for the major electricity demand is the electric resistance (water heater). The other elements represent a small part of the machine power. The rinsing state does not provide almost any potential since its cycles are necessary to provide a quality washing cycle.

Next we present and discuss the revealed control strategies for the manufactures analysis:

The element with the largest potential in terms of power demand reduction is the electric resistance. So if we just turn the resistance off and let the cycle continue as normal, the washing quality will not be the same. Nevertheless if we coupled the washing state time with the resistance control two control strategies can be deduced:

- Switch off the water heater (resistance) and washing timer

The goal of this strategy is to switch off only the electric resistance and let the drum continuing its rotary movement. However to maintain the washing quality, the washing state timer should be stopped when the resistance is switch off. So that at the end of the washing cycle, the linen spend the programmed washing time at the temperature chosen by the user enabling a quality washing.

- Reduce temperature setpoint and increase washing time

This strategy is based on the reduction of the temperature setpoint and to avoid washing quality deterioration the washing time could be increased.A study carried out by the Group for Efficient Appliances [6] shows that there is correlation between the water temperature and the washing time in order to have the same washing quality (with some limits). Another possible strategy could be implemented taking into account the external variable of the water temperature at the entry.

- To Introduce preheated water by another element (ex: boiler with gas, solar panels,…) with a different energy source.
- The introduction of a different heat source would eliminate the need to use electricity when the electricity prices are high. However a connection with the other heating device would require, first the existence of this devices and secondly the additional controls are required to connect the water.

As we can see the manufacturer level allowed to deduce control strategies, which were “invisible for the analysis consumer level”, however these strategies of control will be more difficult to set up because it would be necessary to make modifications on the appliance and/or to introduce additional equipments.

On the other hand these control strategies show the path of how to transform a common appliance into a smart appliance, capable of shifting or modify its operation in a response to electricity prices or to a direct load control.

Conclusion

The language ILCA allows by a simple and intuitive method to determine the possible control strategies of electric appliances that can be applied by demand response programs.

The example of a washing machine showed that based in the equipment manuals and empiric experience the user level analysis allowed determining control strategies that can be directly applied by the users. These control strategies can then be used by demand response programs either as practical consumer actions (to indicate how to shift or reduce equipments electric demand from peak hours) or as inbuilt control devices to shift or reduce the equipment load from peak hours.

On the other hand the manufacturer’s level demanded a more detailed work. Some studies and measurements made available the detailed description of the washing machine by the ILCA language, allowing that advanced control strategies could be revealed. This language showed how advanced control strategies can be applied to new equipments in order to take full benefits of the equipment operation flexibility.

The language allowed compressing all the information about the washing machine operation into a simple graphic easy to understand.

Perspectives

Once the control strategies determined two questions can be raised.

First, which type of communication can be applied to each one of the determined control strategies without damaging or affecting greatly the machine operation?

Secondly, what are the impacts in terms of power relief and energy demand of these control strategies?

A part from these questions an evaluation of the applicability and technical application of the determined controls by the ILCA language should also be made.

References

[1] EuP Lot 6. Eco-design lot 6 : Standby and off-mode losses. Technical report, 2006.

[2] Selina D3.1. Field measurement and awareness survey in shops and stores of new equipment , wp3 d3.1. Technical report, Report elaborated for the EC, http://www.selina-project.eu, 2010.

[3] EuP Lot 14. Preparatory studies for eco-design requirements of eups lot 14 : Domestic dishwashers and wachining machines. Technical report, 2007.

[4] Ecowatt bretagne, http://www.ecowatt-bretagne.fr/, Réseau de transport d’électricité

[5] Ecowatt-provence-azur,http://www.ecowatt-provence-azur.fr/,Réseau de transport d’électricité

[6] EnR – working group Group for efficient appliances. Long?term efficiency targets, technical and economical analyses – washing machines, driers and dishwashers. Technical Report Volume 3, 1995.

Demand Response Using Smart Meters and Home Area Networks in Competitive Retail Markets: Real-World Experience in the Texas Market

Chris King, President, eMeter Strategic Consulting and
Alicia Carrasco, Director, Regulatory Affairs, EMEA, eMeter Corporation

Subject Categories/Keywords: Demand Response; End-use Metering and Home Automation; Smart Appliances, Smart Homes, and Smart Grids

Abstract: This paper reviews the Texas experience with residential demand response, smart meters, and smart grids. Texas has a competitive retail electricity market following the European model. The Texas utilities have installed over 2 million smart meters on the way to 7 million by 2013. Texas consumers were given the ability in mid-2010 to view their detailed energy usage data online. They can also authorize third parties to receive their data for presentment purposes. In addition, consumers can install in-home displays and other home area network (HAN) devices that communicate directly with smart meters using the ZigBee standard approved by the U.S. National Institute of Standards and Technology (NIST). The in-home displays show usage data in real time and can be updated as often as every five seconds. Texas utilities test HAN devices for compatibility with the smart meters that have been installed to ensure proper operation, and several HAN devices from multiple manufacturers have been approved for installation. Finally, using data from the smart meters, Texas retailers offer time-of-use rates to encourage load shifting. These time-of-use rates have three pricing periods: peak, mid-peak, and off-peak. Accordingly, demand response in Texas incorporates energy usage feedback, automated appliance control, and dynamic pricing. This paper will describe the functioning of the market, consumer experiences, and quantitative results.

I. INTRODUCTION

In 1995, the Texas Legislature introduced competition into the state's wholesale markets. The Electric Reliability Council of Texas (ERCOT) is the regional power grid for the majority of Texas, representing 85 percent of the electricity demand in the state, and covering 75 percent of the geographic area of Texas. Under the new law, generation developers not affiliated with electric utilities were permitted to construct and operate new generation facilities and were provided access to the transmission lines of electricity utilities in the state to permit them to deliver their power to wholesale customers.

In 1999, the legislature continued the transition toward competitive energy markets by establishing a framework, shown in Figure 1 on the next page, to allow retail competition in ERCOT portion of the state. Governing boards of municipally owned utilities and electric cooperatives within that area – representing about 25% of the customers – were granted the authority to elect whether and when to open their service areas to customer choice. Utilities in the non-ERCOT areas remain bundled, vertically integrated utilities subject to full regulation of rates and services by the Public Utility Commission of Texas (PUCT).

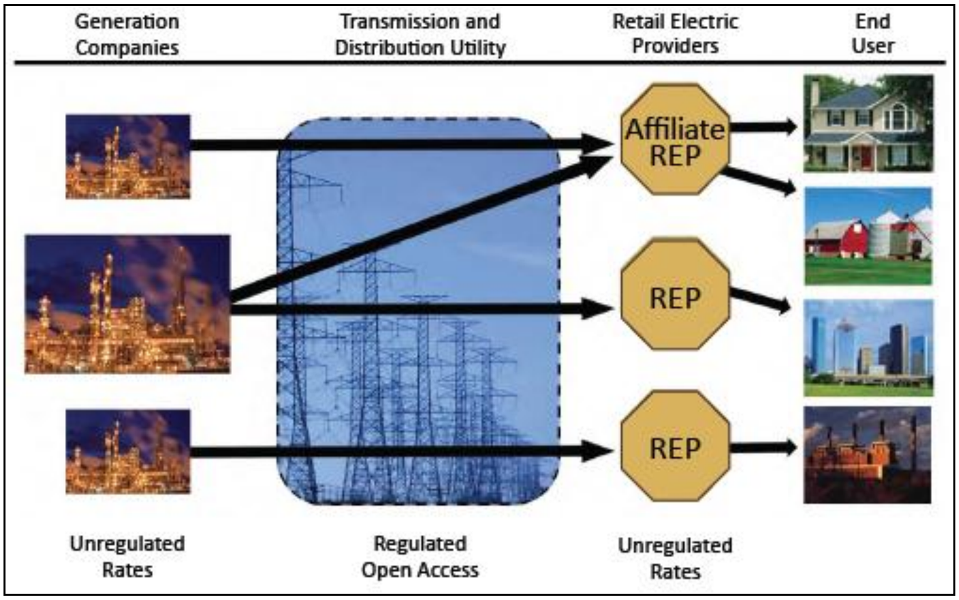


Figure 1: Texas Retail Market Structure, including Retail Electric Providers (REPs)

Retail competition for customers of investor-owned utilities – following the 1999 law – went live on January 1, 2002. The market structure provided that the formerly integrated utilities were required to separate their business functions into three distinct companies: a power generation company (PGC), a transmission and distribution utility (TDU), and a retail electric provider (REP). The power generation and retail electric sectors are, at this point, generally unregulated, with prices and investment decisions determined by the forces of competition. The transmission and distribution sector remains fully regulated by the PUCT, with rates set on a cost-of-service basis and open access guaranteed to all buyers and sellers of electricity.

The state had two major goals in pursuing competitive markets. The first was to manage and reduce electricity costs and prices. The second was to promote the availability of innovative products and services for power consumers.

II. WHOLESALE MARKET

Many experts and financial analysts view the competitive structure in Texas as a successful example of wholesale and retail competitive electric markets.

Generation investment

The market has experienced significant investment in the generation sector, all at the risk and expense of the generation developers. Since 1995, over 37,000 megawatts of new generation has been built and is currently operating in Texas. In recent years, a substantial amount of wind energy has been installed, primarily in West Texas. This increase is shown in Figure 2.

Since 2007, total installed capacity has more than doubled, to nearly 10,000 Megawatts.[1] Work remains to integrate large amounts of wind. ERCOT must have the tools and reserves to adequately handle the intermittency of wind generation. When wind is produced, it generally displaces natural gas-fired generation, and sometimes even coal, resulting in lower natural gas consumption and lower energy prices.

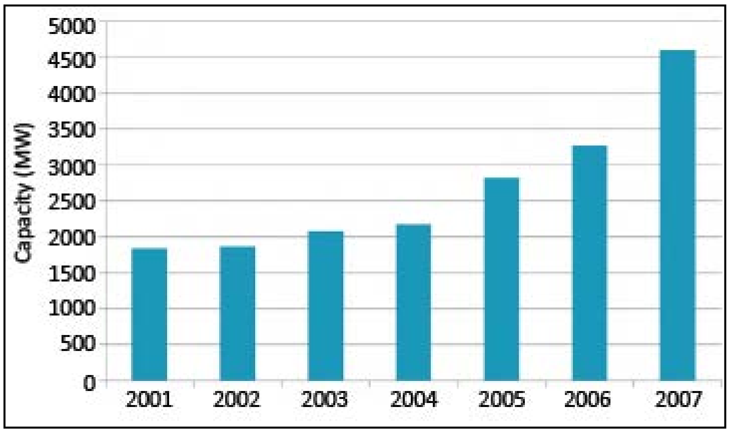


Figure 2: Wind Generation Resources in Texas[2]

Wholesale and retail energy prices

Because Texas's wholesale electricity market has effective competition, prices are driven by the cost of the marginal fuel, natural gas. Natural gas is at the margin, because fuel costs for the other major production sources – coal, nuclear, and wind – are all lower. Effective competition between retailers means that changes in wholesale prices are transmitted through to end consumers.

Natural gas prices during the 2009/2010 time frame were low and stable, resulting in low wholesale and retail electricity prices.[3] The lowest competitive offers for residential service in the Texas retail electricity market are below the regulated rates that were in effect in 2001. The average 2001 rate was 7.6 eurocents (¢)[4] per kilowatt-hour (kWh), the average lowest fixed rate as of December 1, 2010 was 5.4¢ per kWh, and the average lowest variable rate was 5.1¢ per kWh. Variable rates change monthly in accordance with wholesale prices and are lower than fixed rates offered to new customers, because the consumer bears the risk (and gains the lower price) of wholesale price fluctuation.

In most of the service areas in Texas, rates are available at less than 5.7¢ per kWh. The lowest residential rates in the Texas market today are well below the U.S. national average electric rates. This

---

[1] - The Energy Collective, *The Curious Case of the Texas Wind Industry,* February 9, 2011 at http://theenergycollective.com/terynnorris/51416/curious-case-texas-wind-industry.

[2] - Texas Governor's Competitiveness Council, *2008 Texas State Energy Plan*, July 2008.

[3] - Public Utility Commission of Texas, *Report to the 82nd Texas Legislature: Scope of Competition in Electric Markets in Texas,* January 2011.

[4] - At 14 March 2011, the exchange rate was $1 US = 0.7146 **€**.

compares to an average rate of 14.6¢ per kWh for the EU-27 countries.[5] However, because monthly usage in Texas is much higher, the annual bill for a household in Texas averages 912 €, while a typical household in southern Europe with 3,500 kWh annual usage would pay about 531 € and one in northern Europe with 7,500 kWh annual usage would pay about 1,096 €.

III. DEMAND SIDE PRODUCTS AND SERVICES

One manifestation of Texas's success since the opening of the retail market in 2002 is the proliferation of consumer offerings. Due to the features of Texas as a place to do business, all types of customers (industrial, commercial, and residential) may choose from a large number of REPs seeking to meet their energy needs.

In order to manage their risk and cost of electricity, customers have a wide array of products from which to choose, including fixed-price term contracts for as long as five years or products that more closely track the real-time or daily energy market. Larger customers have options to more efficiently use self-generation and demand-response tools to re-sell their electricity back to the market at times of high demand and energy prices. Both large and small customers have options to purchase electricity in a manner that meaningfully impacts their environmental concerns and sensibilities through the purchase of renewable energy products.

Residential customers have extensive choices. For example, consumers can choose from about 30 providers offering almost 100 different product choices. These choices include fixed- and variable-rate offers, short- and long-term contracts, and renewable energy options. In order to gain and retain customers, competitive pressures compel REPs to offer innovative service packages, some of which include energy efficiency products, demand-side management (DSM) options, and customer education programs.

Shopping for electricity has proven popular with customers, with over 40 percent of residential customers and almost 70 percent of commercial and industrial customers, having switched their service to REPs.[6] Commercial and industrial customers have embraced change more quickly than residential customers. This is not surprising, given that the cost of power is often a major expense for such customers. Approximately 80 percent of residential customers have made observable choices in the competitive market. This percentage includes those customers that have switched their service to a REP, those that have remained with their default REP but changed their pricing plan, and those that have moved to a new area in Texas. Residential customers are aware of electric choice and are exercising their option to choose.

Smart metering deployment

Texas legislation enacted in 2005 encouraged the adoption of advanced meters, finding that "new metering and meter information technologies have the potential to increase the reliability of the regional

[5] - EU Energy at http://www.energy.eu/Gas-Electricity-Prices/ as of 14 March 2011, for consumers using 7500 kWh per year.

[6] - *Op. cit.*

electrical network, encourage dynamic pricing and demand response, make better use of transmission and generation assets, and provide more choices for consumers." The Public Utility Commission of Texas (PUCT) adopted regulations in May 2007 that established a framework for the distribution companies to deploy advanced meters.

The three largest distributors in Texas have received PUCT approval of plans for the deployment of smart meters and have begun deployment in their service territories. By November 30, 2010, 2.5 million smart meters had been deployed, and by the end of 2013 approximately 6.1 million smart meters will be installed across the state.[7]

Use of smart meter data

Distributors, retailers, and the wholesale market operator, ERCOT, are beginning to provide tools that will permit customers to realize the benefits of smart meters. In early 2010, the distributors launched Smart Meter Texas, an online tool for customers and retailers to access 15-minute consumption data from smart meters. The interval data is retrieved daily by each distributor and forwarded to the Smart Meter Texas so customers can view their data up through midnight of the previous day.

ERCOT began to use 15-minute consumption data for wholesale settlement in December of 2010, and approximately 1.6 million meters are being settled on a 15-minute basis. This means such customers are no longer settled using class load profiles, and the costs charged to retailers reflect the actual costs created by the actual interval usage of the customer.

Retailers are also beginning to offer products that take advantage of the 15-minute smart-meter data, including prepaid services that permit customers to avoid paying a deposit for electric service and to pay for electricity in smaller increments. Customers in other prepayment programs, such as the one at Northern Ireland Electricity, often choose to pay their electric bills once a week, reducing consumption by as much as 11%.[8] Retailers have initiated pilot programs with customer information devices, programmable thermostats, smart appliances and other technologies that will allow customers to use the information from smart meters to manage their consumption better.

Smart Meter Texas web portal

The Smart Meter Texas web site was built by a consortium of electric transmission and distribution utilties, including CenterPoint Energy, Oncor, and American Electric Power, to give customers with smart meters in the service territories of these utilities more control over their electricity use. Figure 3 shows the data flows.

---

7 - *Op. cit.*

8 - Primen, Inc. *California Information Display Pilot Technology Assessment*. December 21, 2004.

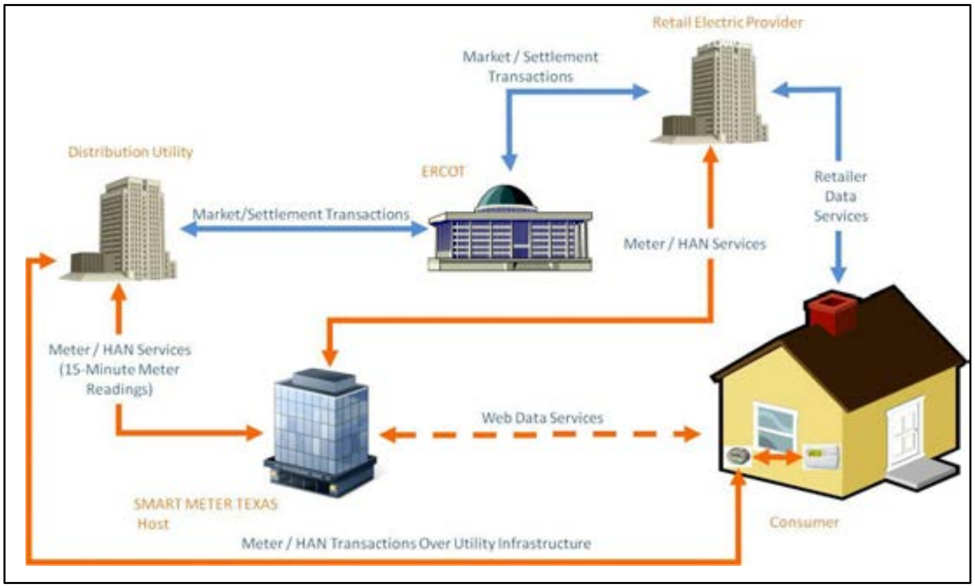


Figure 3: Smart Meter Texas is a centralized portal for data and home area network services

After a testing and acceptance period of up to two months following the installation of their smart meter, consumers can register at www.SmartMeterTexas.com to access detailed views of their electric usage.

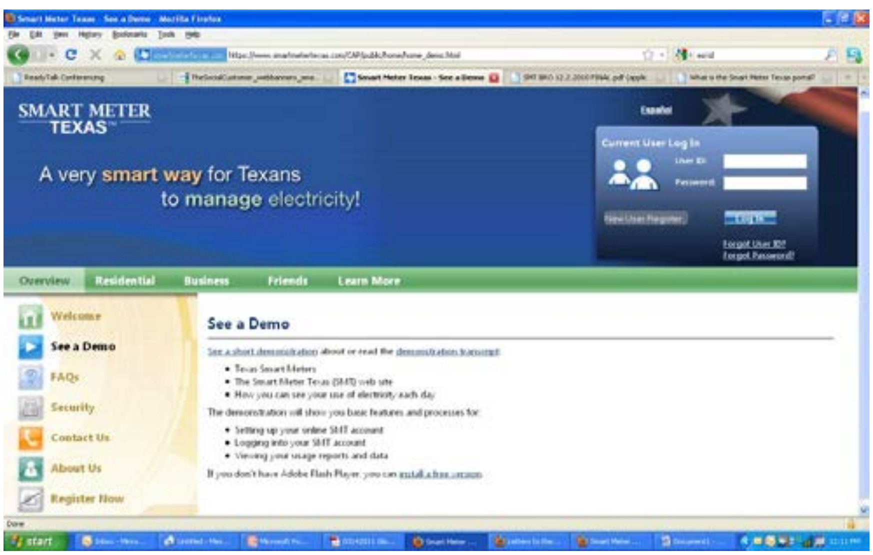


Figure 4: Smart Meter Texas welcome page

The Smart Meter Texas tools allow consumers to see their detailed usage data daily, up to two days earlier. The site includes history in 13-month, 30-day, or 24-hour snapshots down to 15-minute intervals including usage data. They can monitor how electricity is used each day. The goal is, through more efficient use of energy, to achieve a lower electricity bill. The tools also allow consumers to view the home area network (HAN) devices that have been added to their smart meters.

Consumers register on the website by providing their (Electric Service Identifier) ESI ID and Meter Number, which can be found on their electricity bill. An ESI ID is a unique number that identifies the customer's electric service location and may be considered the meter socket in most cases (in the U.S., electric meters are typically mounted in a plug-in socket). The ESI ID is not the same as the customer's account number with the company that bills them. The ESI ID is independent of any particular company and uniquely identifies the service location for use by any authorized energy company in Texas (e.g. a distribution company, REP, or authorized energy services company).

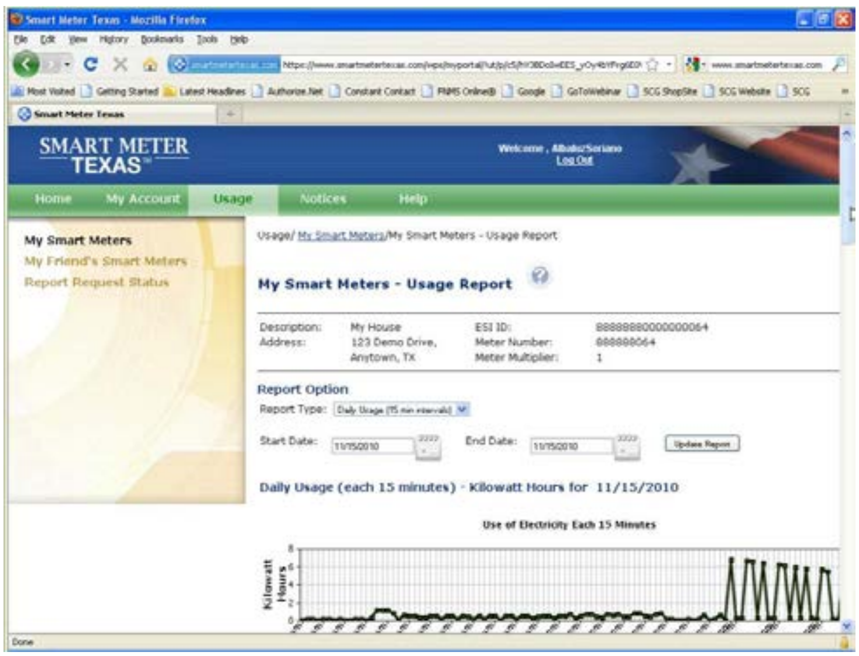


Figure 4: Interval data display on the Smart Meter Texas portal

The Smart Meter Texas portal also allows retail electric providers (REPs) to access their smart meter customers' usage information to support retail offerings such as energy analysis tools, time-of-use rates, and pre-paid service. Through the portal, REPs can also connect Home Area Network devices to smart meters to help consumers better manage their electricity use by remotely controlling smart electric appliances and thermostats, which are under development by a number of manufacturers.

REP offerings: case study of Reliant Energy

Texas has over 30 competitive retailers. The second largest, as measured by number of end customers, is Reliant Energy. Reliant Energy provides electricity and energy services to more than 1.5 million retail customers—including homes, small and large businesses, manufacturing facilities, government entities and institutions across Texas. Reliant is a leader in offering innovative services, but the other REPs are also very active.

In January 2011, Reliant announced its e-Sense™ smart energy solutions and provided a demonstration of its products and services at the Las Vegas Consumer Electronics Show, a rare appearance for a utility.

e-Sense™ is a voluntary, no-cost option. e-Sense customers have detailed information about how they use electricity at home, timely insights about their power use and cost, and the ability to take action to change how they buy and use power. Reliant markets e-Sense to any customer in Texas with a smart meter (more than 2.4 million homes and businesses as of January 2011). The e-Sense products and services use information from the smart meters installed across Texas.

Reliant offers its own consumer engagement portal as an alternative to Smart Meter Texas, called e-Sense Online Account Management (OAM). As with Smart Meter Texas, customers can use OAM to see usage history by hour, week and year. However, OAM offers additional functions: comparison of current usage trends to previous totals, provision of a projected bill amount - before the bill even hits customer mailboxes - and keeping tabs on usage by allowing customers to set a monthly budget. Customers can also stay informed with personal email alerts for usage, estimated costs and bill due date. A closely related option is an iGoogle gadget offered by Reliant (see figure).

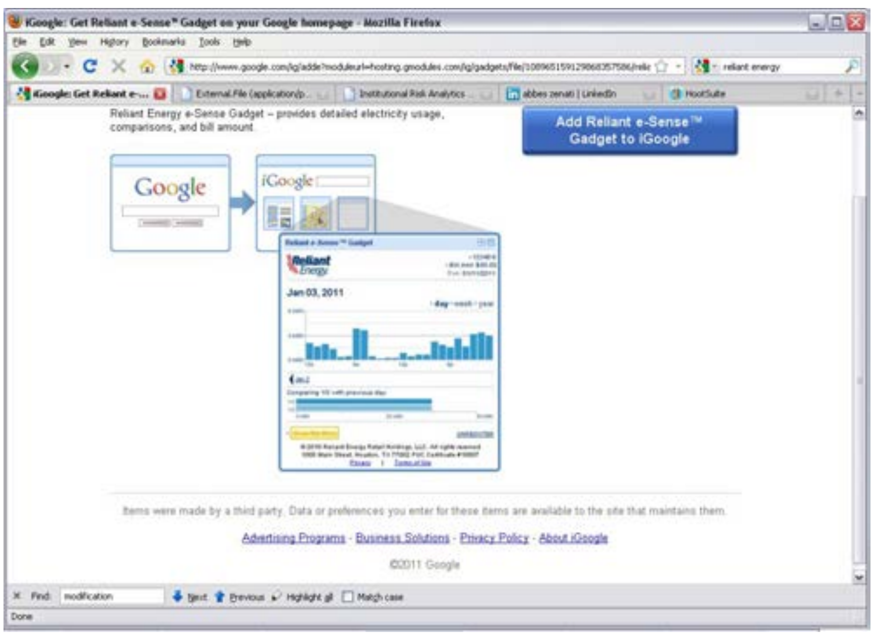


Figure 5: Reliant's iGoogle gadget for viewing energy usage data

Another service is the e-Sense Weekly Summary email. This provides usage information from the previous two weeks, an estimate of total charges for the billing period and energy efficiency tips. According to one customer, "Getting the emails once a week… makes me more aware of how much I'm using and gives me the opportunity to manage my usage better. I know ahead of time - before my bill arrives - whether I need to cut back on usage. The information I get from the email encourages me work harder to try to keep my bill low."

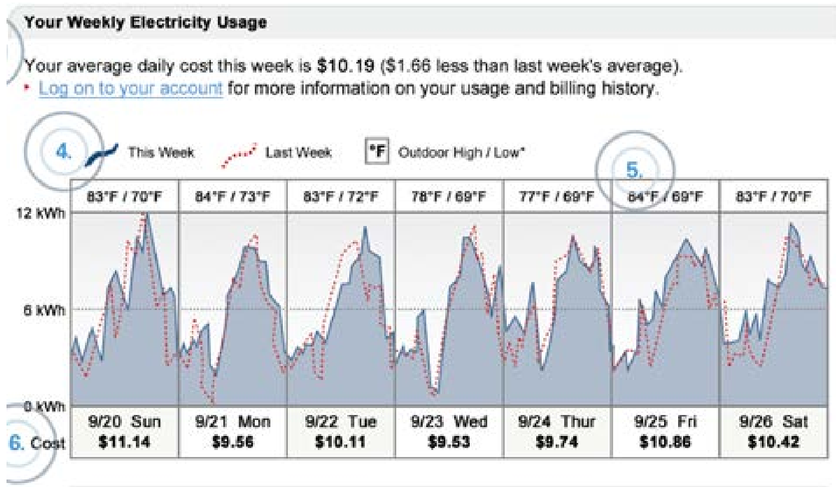


Figure 6: Reliant weekly email to consumers includes 4: legend showing how to compare this week and last week; 5: daily high and low temperature; and 6: daily cost

e-Sense also includes a Time-of-Use plan, a new choice for customers who can shift their usage to lower-priced, off-peak times, helping them save money. Under this plan, the cost of electricity changes during the day based on overall demand for power, allowing customers to benefit from making choices about when and how to use electricity. By shifting high-usage activities - like doing laundry or running the dishwasher - to lower-priced times, customers can reduce their cost.

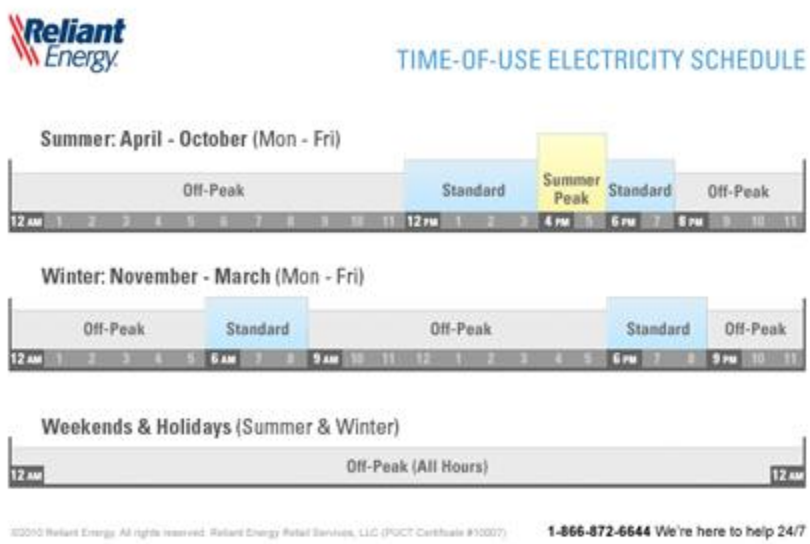


Figure 7: Reliant time-of-use pricing option

Later in 2011, Reliant plans to offer customers the e-Sense Home Energy Monitor - a portable, wireless in-home display that will give customers real-time information about their electricity use and cost.

Home Area Networks (HANs)

The smart meters deployed in Texas have the capability to interact with HAN devices in a customer's premises. The HAN interface in the meters is a ZigBee radio and has the capability of communicating with multiple devices in the home, typically a minimum of five (5). The communications may be directly between the smart meter and smart appliances or through a gateway, or potentially both. Figure X illustrates communication via a gateway. The figure also shows delivery of usage data to the consumer via the Smart Meter Texas portal.

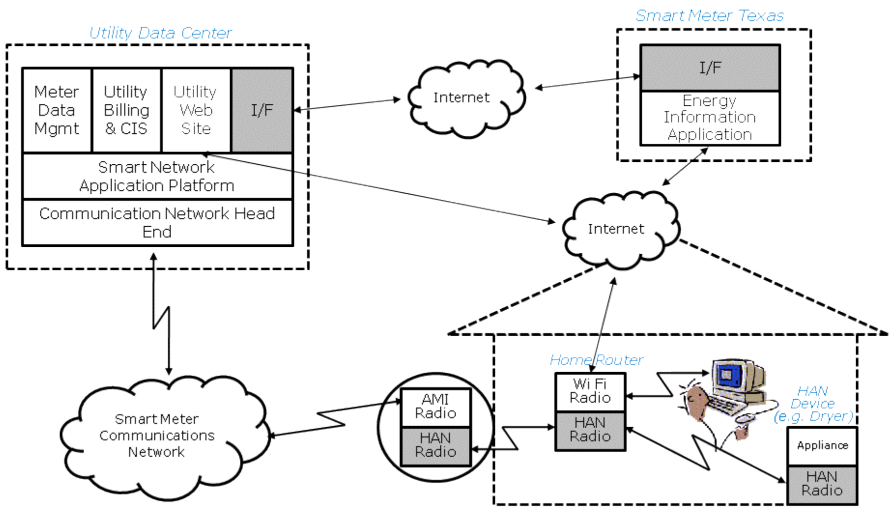


Figure 8: Data interfaces, including HAN interface to a gateway

The ZigBee standard

The ZigBee standard was developed by an open alliance of industry participants, including utilities, technology providers, appliance manufacturers, and others. The standard specifies a full protocol stack for enabling wireless data applications (see figure). The lower layers (physical and medium access) comply with IEEE 802.15.4. On top of this, ZigBee specifies a network layer (for managing network formation, addressing, and routing) and an application layer (for managing device models, application bindings, and application objects). Standardized device activation and configuration procedures are provided by a commissioning framework as part of the standard.

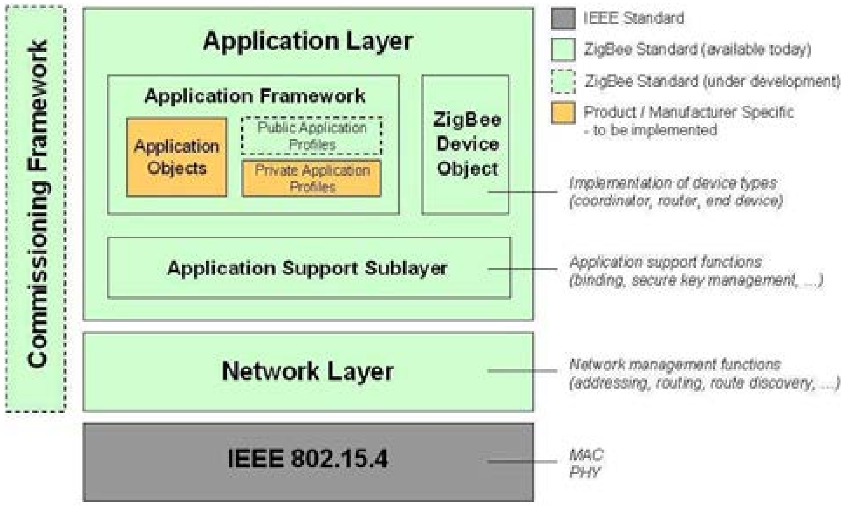


Figure 9: ZigBee protocol stack

Functionality and interoperability of the ZigBee protocol stack are governed by a set of rules called a stack profile. It specifies, for instance, which addressing mechanism is used and which level of security the application implements. At the application layer, interoperability is ensured through public application profiles, which are collections of device descriptions specified by the ZigBee Alliance and that collectively form a distributed application. The ZigBee specification provides standard interfaces and device definitions to allow interoperability among ZigBee devices produced by various manufacturers of electrical equipment, meters, and "smart energy" enabling products

The profile implemented in Texas is called Smart Energy Profile 1.0. This profile defines device descriptions and standard practices for demand response and load management applications in a residential or light commercial environment. Installation scenarios range from a single home to an entire apartment complex. The key application domains included in the initial version are metering, pricing and demand response, and load control applications.

<u>ZigBee devices in the market</u>

The ZigBee Alliance includes over 400 companies, and many millions of ZigBee devices have been sold into the market. Examples in the residential space include Control4 (lighting), Eaton and Tendril (home automation), Golden Power Manufacturing (sprinklers and thermostats), Hawking Technology (home gateways), Kalirel (heating), Mija (fire extinguishers), Nice (shutters), and TSC Systems (home automation). Examples in the commercial space include Mija (fire extinguishers), Philips (lighting), Siemens (building automation), and TAC (building automation).

In the utility space, only a few thousand devices have been installed in connection with smart meters, mostly in utility-led pilot programs. As discussed above, the Smart Meter Texas portal supports provision and operation of ZigBee devices in Texas, and utilities and REPs have deployed several hundred test devices. Manufacturers hope to begin higher volume shipments in Texas later in 2011, with the ultimate goal of selling devices both through REPs and directly to consumers via retail chains such as Best Buy and Home Depot.

To promote market development, the Texas distribution utilities conduct periodic "ZigFest" events. These are open laboratories where device manufacturers can bring their units and have them tested by the distribution utility to ensure the units can communicate with the utility's smart meters. To date, the utilities have tested and verified operation of at least 20 different devices, primarily in-home displays and smart thermostats (used to control air conditioning and electric heating loads).

In the ZigFests, the utilities stress the point that they are not conducting formal certification or qualification tests; they are providing a voluntary service only. There is no requirement for utility approval in order to have devices communicate with the meters, only that the devices meet the technical standards of Smart Energy Profile 1.0.

IV. CONCLUSION

Many U.S. states and countries are pursuing smart meters and smart grids. Texas offers a large and innovative, living laboratory to observe the introduction of new products and services to consumers and development of these markets.

Non-intrusive detection of high power appliances in metered data and privacy issues

Wouter Labeeuw

Geert Deconinck

K.U.Leuven, Department of Electrical Engineering, ELECTA

Abstract

Privacy was already an issue in 1992 when non-intrusive load monitoring was presented. Today, governments encourage distribution system operators towards smart metering implementation, a form of non-intrusive load monitoring. In this paper, a method is presented to detect high-power appliances in metering data with sample periods of seconds and minutes and what can be derived from this information. The second based method uses apparent power information, but it can be done with active power as well. Detection on minute based measurements requires active and reactive power. Afterwards, potential privacy issues are addressed.

Introduction

In 1992, Hart [1] has presented appliance load monitoring in a non-intrusive way. An existing kilowatt-hour meter was extended with a communication unit. Through the detection of steps in active and reactive power, the on and off switching of appliances could be determined. This detection of appliance use patterns raised questions about privacy.

Currently, governments encourage distribution system operators towards smart metering implementation [2]. The steps in consumption are not monitored but only the consumption itself. Smart metering is becoming standard practice. Law researchers already addressed some possible issues regarding privacy [3], but only limited technical publications have addressed the information that can be derived from measured data [4]. Most non-intrusive detection research tends to focus on specialised equipment for the detection of appliances [1, 5].

The total electricity consumption profile of a household can be interpreted when there is knowledge about the distinct appliances. Most appliances are common for many households. The detailed electricity consumption, the time of the day and the day of consumption provide information about the nature of the household, e.g. the number of occupants and their age [6]. Appliance modelling and information extraction from metering data with a sample period of seconds and metering data with a sample period of minutes is addressed in this paper.

Appliance modelling

Households only have a limited number of high-power appliances, most of which contain a heating resistor. Amongst the appliances that give a good impression about the household situation are washing machines, dryers, dishwashers, electrical boilers, electrical cooking plates and ovens. Multiple appliances are required to obtain a detailed view of the household. Appliance models are applied to get this detailed information.

An appliance model consists of a usage model and a consumption model, as presented in Figure 1. The usage model defines whether the appliance is used at that time, what the settings of that appliance are and how the appliance is loaded, using date, time and household information as input. Given those settings, the consumption model generates a consumption profile over time.

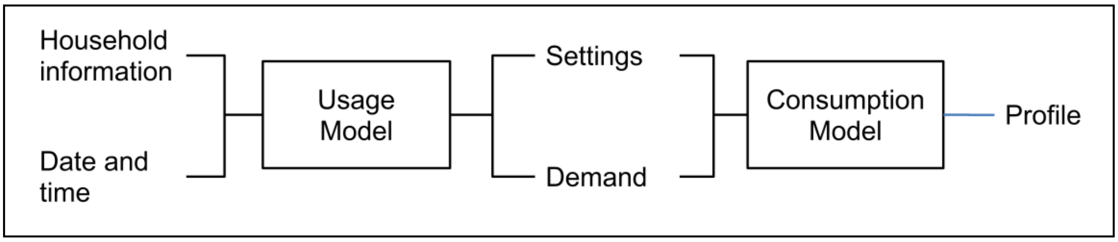


Figure 1: Appliance model

The duration and timing of heating in a high power appliance and the influence of the other internal components, such as motors, give the appliance a specific signature. Different appliance settings and demand give a variation on the signature.

Appliances can be detected from the total load profile of a household by applying the inverse method. Not being able to detect an appliance also says something about the household. Some types of households do not have e.g. a dishwasher. The variations in the load signature of the appliance give an indication about the settings and the demand of the appliance. Date and time information, together with the settings and the demand, provide household information.

Variations on the load signature of an appliance can only be detected if the resolution of the data is sufficiently high. The programme duration as well as the power at certain time steps shows how the appliance is used.

High resolution metering data (sample period of seconds)

Appliance detection

The measured apparent power with a sample period of six seconds is displayed in Figure 2. The measurements were done at the meter closet. Three distinct appliances can be discovered by matching the specific appliance signature with the data: a washing machine, an oven and a coffee machine.

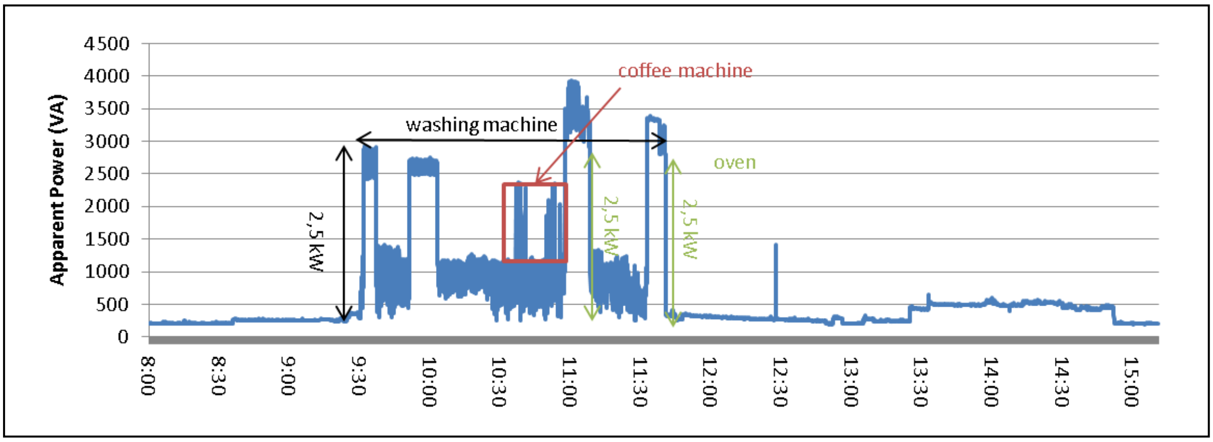


Figure 2: Metering data with a sample period of seconds

In general, washing machines have a heating resistor of approximately 2 kW and a motor of 500 W. The motor swings the laundry around and spins it dry at the end of the washing cycle. Only at the spinning stage, the motor runs at full power for some time. Manufacturers build universal motors, brushless DC motors and three phase induction motors into residential washing machines. In 2005, 94% of all washing machines had a universal motor, 5% had a three phase induction motor and 1% a brushless DC motor [8]. Typically, universal motors are TRIAC-controlled and use phase cutting as a pulse width modulation technique to limit the power. Phase cutting creates a lot of distortion in active and reactive power. The apparent power distortion can be seen in Figure 2, when the washing machine is running. The same kind of distortion is observed in active and reactive power but the distortion is bigger in the reactive power component. When the motor is swinging, the reactive component of the motor is larger than the active component. This makes the power signature of the washing machine unique and easy to detect in metered data.

The input power of ovens typically ranges between 1.8 and 6.5 kW (2.5 kW kW in this particular case). An oven does not really require reactive power. The only reactive power use of an oven is the small fan to get the air circulating when asked. Now how can one distinguish an oven from a stove? They have about the same power. The main difference between the signature of an oven and a stove is the on/off time [1]. An oven stays on for several minutes and then switches off for several minutes. A stove has less thermal inertia and switches on and off in several seconds. An iron behaves in the same way, but is used on different points in time.

Coffee machines have a heating resistor with a power of 0.6 up to 2 kW and exhibit lower thermal inertia than stoves and irons. Therefore, their switching frequency is higher: switching on and off in seconds, when the water in the machine needs to be heated. Coffee machines also stay off for a longer period of time and heating only restarts when the water gets cold. The behaviour of instant coffee makers is quite distinctive. First, a small reservoir of water is preheated up to a certain temperature. Then the selected programme is executed and additional heating occurs. This behaviour is clearly observed in Figure 2: at 10h36, the instant coffee machine is switched on and gets preheated, at 10h37 the coffee is made and the water gets preheated again.

If enough information about typical signatures of appliances is available, it is possible to extract the time of use and the type of appliances from the measurement data. The detection was done manually for this paper, but the models allow the detection of the appliances by means of pattern matching. The frequency at which an appliance is used, reveals information about the household itself. For instance, the frequency of the use of a washing machine tells something about the number of occupants of the household, as shown in Table 1.

Table 1: Correlation between average washes per week and household size [7]

Occupants	1	2	3	4	5	> 6
Washes per week	2.1	3.4	4.9	6.4	6.3	7.0

Appliance usage

As shown in the previous section, the time of use and the type of appliances can be extracted from metering data with a sample period of seconds. However, these measurements also reveal how the appliance was used. Variations in the specific power signature of an appliance give a good indication about the settings and the load of an appliance, but the resolution of the metering data needs to be high enough.

As an example, the washing machine from Figure 2 will be explained. From the detailed consumption profile, settings and demand can be determined as shown in Figure 1. For washing machines, the settings are the selected programme and the washing temperature. Typical programmes are “cotton”, “easy care”, “mix”, “wool”, etc. Typical washing temperatures are 30, 40, 60 and 90 °C. Most washing machines do not have a demand set point, except for the machines that weigh the laundry before starting. In this case, the demand is the amount of laundry, in kilograms, placed in the machine.

The total duration of the washing programme in Figure 2 is around 2 hours and 10 minutes. There are two heating cycles, which means that a prewash was selected. Standard cotton programmes with prewash take about this time to finish. Heavy programmes can take up to 3 hours. Short programmes allow less load and will only need 1 hour or less to finish. The duration varies a bit from machine to machine, but variations are small. The next step is to determine the temperature of the washing machine. The temperature can be derived from the time used to heat up the water. The prewash took 5 and a half minutes, which is the equivalent of a 40 °C wash for a machine with a capacity of 5 kilograms. The wash itself took 12 minutes, this is a 60 °C programme for a machine of 5 kilograms.

The heating resistor of a washing machine with a capacity of 6 kilograms would have needed 14 minutes to heat up the water. The selected programme was a cotton wash of 60 °C with a prewash of 40 °C.

The same exercise can be done for several other appliances. The household information derived from one appliance can be used to help detecting other appliances. Drying, for instance, usually takes place after washing.

Low resolution metering data (increasing sampling periods)

Figure 3 shows what happens if the sampling period increases from 30 seconds to 1, 5, 10 and 15 minutes. Fast switching appliances become undetectable. The coffee machine, for example, is still detectable in the 30 seconds and 1 minute data, but the information of the coffee machine is gone in the 5 minute data. The same is true for the washing machine. The total duration of the programme can be derived from the 30 second and one minute data, even the duration of the heating is still visible. At lower sampling frequencies the distortion that made it possible to find washing machines can no longer be observed, thus making it harder to distinguish e.g. some programmes for washing machines from some dryer programmes, as shown in Figure 4. The main difference in dryer programmes and washing machine programmes is the amount of heating energy needed. Dryers exhibit a much higher electricity demand and their programmes are usually shorter. In data with a sampling period of 5 minutes, some distinction can still be made, but it is impossible to do so if the sampling frequency decreases even further.

The dimensional reduction by the increasing sampling period has to be countered by the introduction of an-other detectable parameter. When both the active and the reactive power are considered, it is possible to identify some appliances again. Figure 4 shows the active and reactive power of a short washing machine and tumble dryer programme, the measurements were performed on the individual appliances. Dryers have a small negative reactive power, indicating capacitive behaviour, while washing machines have a rather large positive reactive power, i.e. inductive behaviour. A sudden increase in active power, together with a sudden increase in inductive reactive power, indicates the use of a washing machine. The slightly capacitive behaviour of the dryer will be harder to detect, the change in power is less explicit. It will be harder to distinguish a dryer from e.g. a stove that heats for a short while.

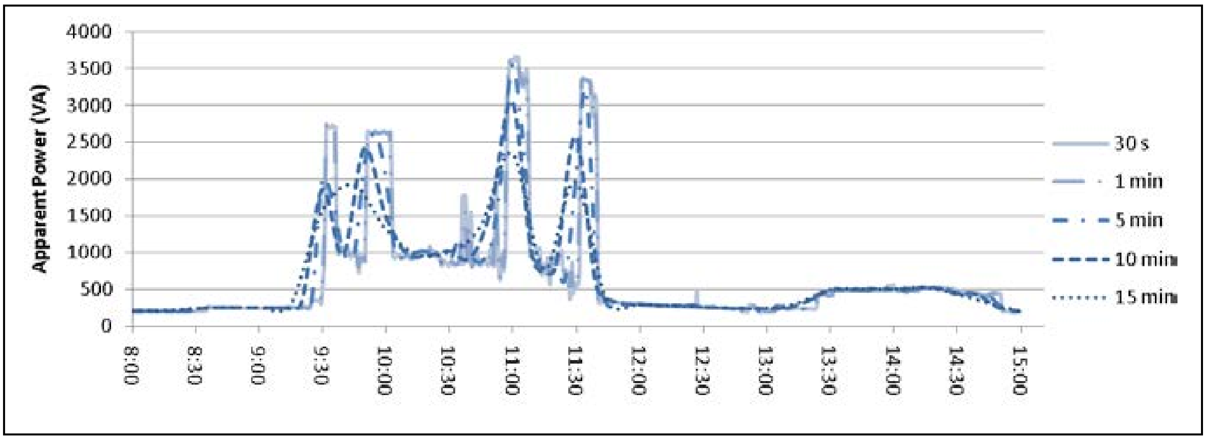


Figure 3: Metering data for several sampling periods

Figure 5 shows what the load signature of a washing machine looks like in metered data: active power (P) and reactive power (Q) for six seconds based sampling data and fifteen minutes based sampling data. The sudden transition in inductive power indicated the use of a universal motor. The measurements were done at the meter closet of a house.

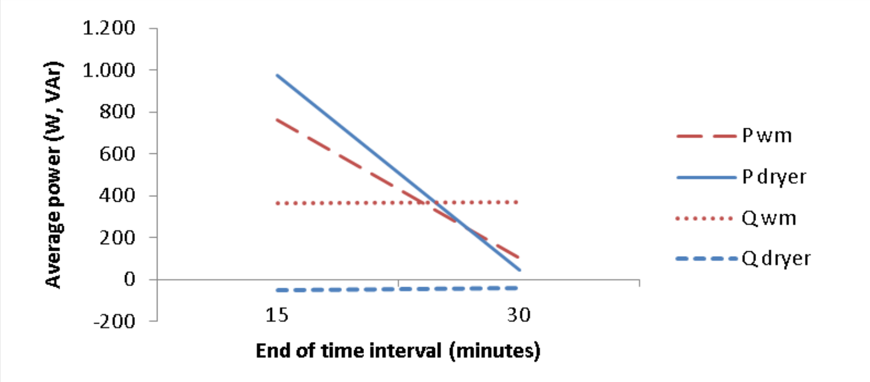


Figure 4: Washing machine (wm) and dryer: active and reactive power, fifteen minute sampling period

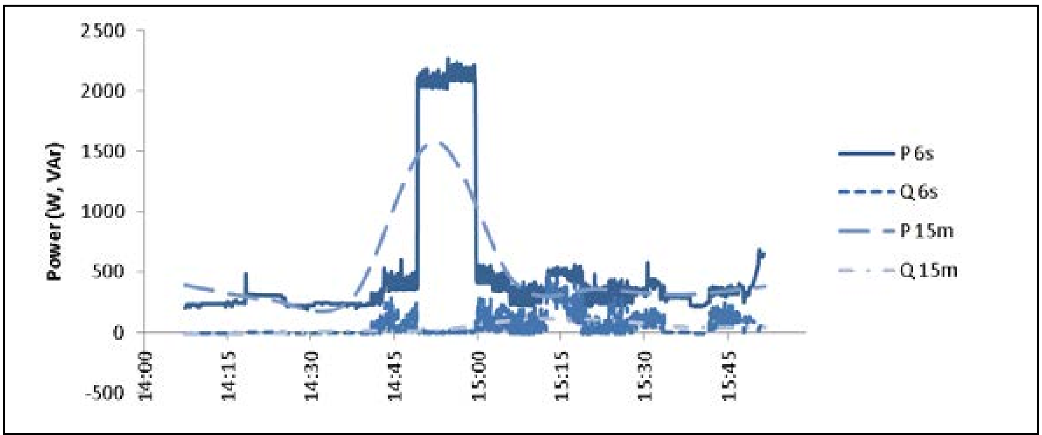


Figure 5: Household active and reactive power for six second and fifteen minute sampling period

Privacy

Cambridge Dictionaries defines privacy as *"someone's right to keep their personal matters and relationships secret"*. Detailed electricity consumption measurements and appliance information provide insights about ones lifestyle. The metered data is not stored at the customers home, but in a company providing metering services. In this way, the customer loses control about their own data.

Although distribution system operators are capable of detecting appliances in metered data, they are in general not interested such data. The main purpose of smart meters to them is to get insights about their own network. On the other hand, malicious hackers might try to gain access to the servers of a distribution system operator and sell the gathered information to other parties. Also, new parties will step up and provide energy management boxes that will allow customers to consult their consumption online.

Google and Microsoft, for instance, each provide an energy management tool: Google PowerMeter™ and Microsoft® Hohm™. When appliance detection is possible, they will likely add this feature to their tool and present advertisements next to the consumption profile. In this way, they could advertise e.g. a number of dishwashers when the dishwasher of the customer is broken. Foreknowledge is an advantage for sellers, since they know the customers needs and can adjust their prices to it. Additionally, insurance companies might, for instance, be interested in ones' life pattern. It is very likely that people with an unhealthy life pattern will have to pay higher fees for e.g. life insurance than people with a healthy life style. This undermines the purpose of insurances: spreading risk. These are only some of the possibilities of using information from metered data.

Critical remarks

The performance of household appliances improves constantly and this has an impact on their detection. Brushless DC motors and three phase motors are gaining market share amongst washing machines, decreasing the use of universal motors and the phase cutting control. Differences in reactive power will be less explicit and this will make it harder to detect some appliances in metered data.

Some manufacturers already found a way around this "problem": they introduced measurement plugs. The plugs measure the energy consumption at the plug and then send it to a central point. At the central point, the plugs are tagged with the with the corresponding appliance. In this way, users obtain information about the energy consumption of certain appliances. The plug can also be automatically switched on or off from the central point in order to reduce stand-by losses [9]. Needless to say that these plugs give insight in the energy consumption of a household, which may lead to privacy issues.

Metering data will still give information about households, even when specific appliances can not be detected. Retired people are at home during the day while most people are out to work. Children in Belgium have the afternoon off on Wednesday. If a household consumes more energy on Wednesday afternoon than on other weekdays, it could be concluded that the household has children or that someone in the household is a teacher. Energy consumption rises with the number of inhabitants of the household, etc. Even clustering techniques can be used on the measured data [10].

Kalogridis et al. [11] presented a way to get around these metering issues. They propose the use of a power router and a load signature moderator to hide, smooth or obfuscate electricity consumption. The main drawback of this approach is the price. The price of lead acid batteries starts around 150 USD for one kWh of storage with 300-500 cycles and 80 percent depth of discharge. Lithium and Nickel-Metal Hydrid batteries have more cycles, but cost hundreds of EUR [12]. As a result, batteries are not an option for the general public.

Conclusions

Most households have a common set of high power appliances. The detection of those appliances gives insight about the household itself, e.g. more washes per week means more inhabitants. The appliances themselves can be detected in the metering data if the sampling period of metering is sufficiently high. The detection of a washing machine, an oven and a coffee machine by means of power consumption and switching frequency is demonstrated in this paper. Even specific settings of appliances can be resolved: an example of the detection of a washing machine programme is explained in this paper. The detections were done manually for this paper. In future work, the appliance models in combination with pattern matching algorithms will be explored.

Appliances which incorporate a heating resistor are still easy to detect in metered data, when the sample period is several minutes. However, another parameter has to be added to the metering data in order to distinguish appliances. The reactive power or reactive electricity consumption, for instance, originates from other components in the appliance, and provide a typical signature.

Even without the detection of appliances, specific information about the household can be derived from the metering data, based on the time of electricity consumption. Obfuscating metering data is possible but too expensive for most household families.

Acknowledgements

This work is supported by the Ministry of Science (Minister I. Lieten) via the project Linear organised by the Institute for Science and Technology (IWT).

References

[1] G.W. Hart. Nonintrusive appliance load monitoring. Proceedings of the IEEE, 80(12):1870-189, December 1992.

[2] C. Cuijpers and B.-J. Koops. Het wetsvoorstel 'slimme meters': een privacytoets op basis van art. 8 EVRM. Universiteit van Tilburg, Centrum voor Recht, Technologie en Samenleving, Oktober 2008.

[3] B.-J. Koops and C. Cuijpers. Begluren en besturen door slimme energiemeters: Een ongerecht vaardigde inbreuk op onze privacy. Privacy & Informatie, 6(1):2-7, December 2009.

[4] L. Farinaccio and R. Zmeureanu. Using a pattern recognition approach to disaggregate the total electricity consumption in a house into the major end-uses. Energy and Buildings, Elsevier, 30: 245-259, 1999.

[5] C. Laughman, K. Lee, R. Cox, Shaw S., S. Leeb, L. Norford, and P. Armstrong. Power signature analysis. Power and Energy Magazine, IEEE, 1(2):56-63, March 2003.

[6] E. de Groot, M. Spiekman and I. Opstelten. 361: Dutch Research into User Behaviour in Relation to Energy Use of Residences, PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, October 2008

[7] M. Presutto, R. Stamminger, W. Mebane, R. Esposito, S. Faberi, R. Scialdoni ans L. Cutaia. LOT 14: Domestic Washing Machines and Dishwashers, Tasks 3 – 5, Preparatory Studies for Eco-design Requirements of EuPs, December 2007

[8] M. Presutto, R. Scialdoni, L. Cutaia, F. Lombardi, W. Mebane, R. Esposito and S. Faberi. LOT 14: Domestic Washing Machines and Dishwashers, Task 6 – 7, Preparatory Studies for Eco-design Requirements of EuPs, December 2007

[9] http://www.fifthplay.com/ESS/fifthplay-EnergySmart-Solution/How-does-it-work.html, Januari 15nd 2011

[10] G. Chicco, R. Napoli and Federico Piglione. Comparisons Among Clustering Techniques for Electricity Customer Classification. Transactions On Power Systems, IEEE, vol. 21, no. 2, May 2006.

[11] G. Kalogridis, C. Efthymiou, S. Denic, T. Lewis and R. Cepeda. Privacy for Smart Meters: Towards Undetectable Appliance Load Signatures. First International Conference on Smart Grid Communications (SmartGridComm), IEEE, Gaithersburg, MD, USA, November 2010

[12] S. De Breucker, E. Peeters and J. Driesen. Possible applications of Plug-in Hybrid Electric Ships. Electric Ship Technologies Symposium, IEEE, 310-317, Baltimore, MD, USA, April 2009

SmartRegions: improving energy efficiency prospects of smart metering through collaboration and innovative services

Henk van Elburg

NL Agency

Abstract

Smart metering is rapidly gaining momentum in Europe, thanks to the Energy Services Directive (ESD) and the 3rd Energy Package. Although, considerations for large-scale rollouts take place in many Member States, it's hypothesized success for energy saving and/or peak load reduction should not be taken for granted. Smart meters can only contribute to energy efficiency, if they come public accepted and in line with truly innovative smart metering services. For that reason, a new Intelligent Energy-Europe dissemination project, named SmartRegions, collects and promotes best implementation practices on smart metering and innovative services. Recently, SmartRegions published its first European Landscape Report, analyzing the development of smart metering regulation and metering services in the Member States. As an example, this paper focuses on the experiences in one of the Member States, the Netherlands, to underline that energy saving prospects of smart metering will be more uncertain without these preconditions.

Until recently the Netherlands appeared to be on track for a high-tech and mandated rollout of smart meters. However, intense opposition from consumers' organizations and privacy watchdog groups slowed down this process of regulation and innovation and stimulated the government to switch from a top-down policy implementation to a more collaborative approach with stakeholders and consumers' organizations. Within a new legal framework based on voluntary acceptance by consumers, smart meters are considered now more likely to contribute to increasing energy efficiency, compared to the initial proposed mandated rollout. These learning's can inspire other countries to anticipate and avoid similar setbacks which could eventually endanger the ESD and the EU-target of at least 80% of consumers equipped with a smart meter by 2020.

Introduction

Backed by rising energy demands and fears over security of supply and climate change, smart metering is attracting a lot of interest across the world. Europe is expected to become a world leading centre of this development, thanks to the European Services Directive (ESD) and the Third Energy Package. The 2006 Energy Services Directive laid the foundation for a Europe-wide legislation for smart metering, by requiring individual energy meters to be installed under specific conditions and standards to result in frequent and understandable energy bills. The 2009 Third Energy Package will accelerate the penetration of smart electricity metering in EU Member States by setting a target of at least 80% of all households to have a smart meter by 2020, given a positive economic assessment.

Although, considerations for large-scale smart meter rollouts take place in a growing number of Member States, public acceptance and hypothesized energy savings should not be taken for granted. Recent experiences in the Netherlands demonstrate that smart metering can only contribute to increasing consumer involvement and effective household energy savings if smart meters are publicly accepted, future-proofed, standardized and with facilities for direct feedback to the consumer. Without meeting these preconditions in, rollout and energy efficiency prospects will be much more uncertain.

By elaborating on these experiences and lessons learned in the Netherlands, this paper can be valuable for stakeholders from other Member States who also face (and perhaps fear) growing public rejection of the imposition on them of smart meters. In addition, the solutions adopted in the Netherlands to learn together with relevant stakeholders and subsequently arrive at better policy proposals that also acknowledge end-user needs and ensure more promising prospects for energy savings, can help other Member States to avoid similar (political) setbacks and develop regulatory frameworks that are more likely contribute to consumer satisfaction and increased energy efficiency.

This paper starts with a brief introduction on smart metering and a short overview of current European Member States where large-scale smart meter penetration is already underway or being considered, following the requirements of the ESD and the Third Energy Package. This overview is extracted from the European Smart Metering Landscape Report, a deliverable of the SmartRegions project. This project, funded by Intelligent Energy – Europe (project number IEE/09/775), focuses on the innovative smart metering services, such as informative billing and feedback, variable tariffs and load control services, that are the most potential to bring energy savings and peak load reduction. SmartRegions aims to inspire and encourage energy utilities, energy service providers as well as law makers across Europe to initiate the development of effective smart metering policies and innovative smart metering services by:

1. Monitoring the smart metering landscape in European countries, and giving recommendations for regulatory frameworks.

2. Defining the best practices of innovative smart metering services by analysing their economic, environmental and social costs and benefits.

3. Promoting the best practices of innovative smart metering services and exemplary smart metering regions as models for other Member States and regions.

The European Smart Metering Landscape Report is a comprehensive report on the developments of smart metering and metering services in Europe and consists of in-depth country profiles of all EU Member States and Norway together with case studies of related services for consumer feedback and peak-load shifting[1]. As an illustration from this report, the main section of the paper elaborates on the experiences in the Netherlands, leading to the political climax in 2009 and defines the most important causes. The paper ends with a brief restating of important preconditions and advice for stakeholders in other Member States for an easier and more effective rollout.

Smart metering characteristics and European overview

Traditional static meters provide less than perfect information for both consumers and suppliers. Consumers are generally only aware of consumption on a monthly or even less frequent basis, unless they make time-consuming efforts to monitor the readings on their meters frequently. Also, most suppliers only know how much energy a household consumes after a manual meter read. In addition, difficulties arising from this limited data accuracy cause many disputes over bills, thereby possibly also hindering switching between suppliers and market competition.

Smart meters eliminate these issues for consumers and suppliers by adding two dynamic key features to the functionality of the static traditional meter:

1. storage of accurate metering data at specified time intervals and

2. automatic two-way communication between the consumers' smart meters and the operating system of the network operator / supplier.

By integrating storage capacity and communication technology, the smart meter allows for a radical change in customer-utility relations. In conjunction with smart technology, utilities can adopt pre-pay or innovative time-of-use pricing plan options that incentives customers to use power more wisely. Smart meters also enable consumers to track their usage in real time and better understand their power habits via in-home display units, web-based interfaces or both.

---

[1] The European Smart Metering Landscape Report can be downloaded free of charge from the project's website www.smartregions.net.

The benefits from a rollout of smart meters potentially fall to all actors:

1. To consumers in terms of more frequent and more accurate bills, (near) real-time information to enable household energy savings and facilitation of new energy services.
2. To suppliers in terms of more frequent and accurate information and reduced operational costs to serve.
3. To network operators in terms of more efficient network operation and capacity control.
4. Finally to society in terms of a better functioning energy market, less environmental pollution and reduced carbon emissions.

The implementation of smart meters is also an important first step towards the introduction of smart grids. Smart grids and smart meters are generally conceived as a set of allied tools to help utilities to balance loads across their electricity networks and consumers to manage their energy demand more effectively. Smart grids integrate the actions of all users connected to an electricity power system, employing communications, innovative products and services, and intelligent monitoring and control technologies to:

1. Help utilities to efficiently manage the full array of power generation assets, including traditional generation facilities and renewable sources such as wind turbines, to meet customer needs.
2. Provide consumers with more information about their own usage and peak demand so they can adjust their behaviour.
3. Reduce the environmental impact of power generation through incentivizing customers to reduce electricity use and/or shift electricity usage from peak to off-peak hours to avoid running costly fossil-fuelled peak generation units.

European overview

The adoption of smart metering in Europe is highly dynamic and to a large extent driven by regulations, the European Smart Metering Landscape Report shows [4]. Due to EU legislation such as the Energy Services Directive and the 3rd Energy Package, a majority of the countries in Europe have or are about to implement some form of legal framework for the installation of smart meters. Countries such as Denmark, Finland, France, Ireland, Italy, Malta, the Netherlands, Norway, Spain, Sweden and the UK are ‘dynamic movers.’ They have either decided already about a (mandatory) rollout, or there are major pilot projects that are paving the way for a subsequent decision. Market drivers such as Germany, Czech Republic or Romania have not established legal requirements for a rollout. Utilities nevertheless go ahead with the installation of electronic meters either because of internal synergetic effects or because of customer demands. In other countries the situation is more ambiguous with ongoing intensive discussions but without a clear decision yet. Finally, there are ‘waverers’ and ‘laggards’ where corresponding initiatives have either just started or where smart metering is not yet an issue. However, even in this latter group it is likely that EU legislation will soon result in policy action.

The Netherlands is the first EU Member State to decide for a (partly) voluntary-based rollout of smart meters, after fierce opposition from consumers’ organizations and privacy campaigners. Since government-mandated rollouts can be considered as the preferential method to reap the most benefits of smart metering, important questions arise about the significance of this development for future rollout decisions in other Member States. Will the ‘Dutch dénouement’ lead to a similar reaction in other Member States? And more importantly, will a tendency towards voluntary based rollout schemes jeopardize the initially foreseen economic and environmental advantages of widespread smart metering, as was intended by the ESD?

These questions may be hard to answer at the moment, although similar discussions are starting to take place in other Member States such as Germany and Austria. However, a choice of a voluntary instead of a mandatory rollout does not automatically endanger the energy saving benefits of smart metering as intended by the ESD. On the contrary; the Dutch collaboration with important societal stakeholders for a policy that meet end-user needs better and the pioneering route to a voluntary rollout now offers an alternative with good prospects for a widespread rollout of smart meters and promising energy savings. Overall, it must be realized that a mandated rollout only ensures a full penetration of smart meters, but offers no guarantee for successful consumer involvement and widespread energy savings.

Smart metering regulation in the Netherlands

In order to understand the argument for a voluntary based rollout as an equally effective strategy as a mandated rollout for widespread consumer involvement and effective household energy management, the course of events in the Netherlands will be presented in more detail as a chronological overview of events, an analysis of decisive factors, and finally the switch to a more cooperative approach following a voluntary rollout.

Chronological overview

The Dutch government had already started thinking about introducing smart meters in **2004** in an effort to correct the administrative problems with household energy billing that followed the liberalization of the Dutch energy market. As time went by, other important smart metering drivers surfaced such as facilitating more market competition (easy switch for consumer), operational efficiency for market parties and -last but not least- energy savings for consumers. Limiting peak load demand (e.g. on hot summer days) was, and still is, a less important driver in the Netherlands.

In **2007** the government launched its first comprehensive legal proposal (bill) to change the national Electricity and Gas law in order to improve the functioning of the liberalized national energy market for consumers and small business users and to comply with the ESD-directive. The most fundamental part of this proposal was the restructuring of the national meter market. The key issues of the law proposal were:

1. All 7 million households and small business users will be equipped with a smart meter.
2. The public grid operators will own the smart meters and pay for the rollout, partly from the current meter tariff.[2]
3. The smart meter tariff will become regulated for consumers and small businesses and this tariff should remain unchanged or even drop.
4. The energy retailers / suppliers will be responsible for all customer related processes and the management of the metering data.
5. The smart meters must comply with basic functionality and technology, defined in a regulated technical agreement and a smart meter industry standard.

The government opted for a mandated rollout in 2007, because it was believed that in a liberalised energy market without further regulation, a smart metering rollout would probably reach no more than 30% penetration. In the case of such a partial penetration, the smart meter benefits would probably not be fully realised. Also, the requirements set by Article 13 of the ESD for individual metering and frequent billing (Energy End-use and Energy Services directive, 2006/32/EC) were interpreted as a demand for smart meters.

In **2008** the proposed mandated meter rollout was intensely discussed in public before being debated in the Lower House of the Dutch Parliament. In Particular, the Netherlands' main consumer organisation, Consumentenbond, opposed the new law, mainly because of privacy concerns.

2 To date the meter charge has not been regulated and network operators have increased the monthly tariffs by up to 100% since 2001. The Dutch Competition Authority stated in 2006 that it could not believe there is a convincing relation between the increased tariffs and actual costs.

Moreover, Consumentenbond questioned the energy saving claims made for the smart meter. Finally, on July 3rd in 2008 and after intense discussion, the Dutch Lower House conditionally accepted the proposed law for the introduction of smart metering in The Netherlands. Important conditions required by the Lower House were related to extra meter requirements in favour of energy saving and own-generation of electricity and a two-year trial period for experience purposes.

In **2009** after three terms of heated political debate and renewed vigorous campaigning by Consumentenbond, privacy watchdog groups and even on national public television, the Dutch Senate declined to approve the mandated roll out of smart meters. Fears that data on energy consumption could be misused curtailed the compulsory introduction of the meters in the Netherlands. Dutch consumer and privacy organisations were concerned that information relayed as frequently as every 15 minutes could allow criminals or utility companies to see when properties were empty or when householders had bought expensive new appliances. In the end, the Dutch Senate considered a mandated rollout of smart meters being a violation of the right to privacy as guaranteed by Article 8 of the European Convention on Human Rights. In weighing the pros and cons of a mandated rollout in relation to these privacy / security concerns and poor energy saving guarantees, the Dutch Senate also considered the mandatory nature of the roll-out disproportional: refusing a smart meter would be considered an 'economic offence', punishable with a fine up to € 17,000 or six months in prison. The government was forced to back down and promised a compromise bill based on a voluntary rollout of smart meters.

In **2010** a compromise to the smart metering bill was presented in the Dutch Parliament. This compromise version built on an obligatory providing of smart meters by the grid operators, but a voluntary acceptance by consumers. To regulate the voluntary part of the rollout for privacy reasons, the bill offered four legal options for a consumer in accepting a smart meter:

1. The option to refuse the installation of a smart meter and keep the 'traditional' meter.

2. The option to have a smart meter fitted (or once it has been installed), but opt out of sending automatic meter readings (smart meter functions as a traditional meter, a meter reader is still required).

3. The option to have a smart meter fitted, but with a fixed set of automatic meter reading occasions (bi-monthly consumption and cost reports, annual billing, switching energy supplier, remove to a new house).

4. The option to have a smart meter fitted with full automatic smart meter reading, which is (of course) the preferred option for the government and energy market players.

At the beginning of **2011**, this compromise was accepted in both Chambers of the Dutch Parliament. Also consumers' organizations and privacy campaigners now expressed their contentment with the bill, providing the hard-won freedom of choice for consumers. After a two year delay, noisy civil liberty campaigns, public indignation and finally an awkward u-turn by the government, the Netherlands now has a legal rollout scheme in place.

Defining the decisive factors

How could this happen? How could a country that was initially seen as one of the most advanced smart metering markets in Europe (and indeed appeared to be on track for a fast and mandated national rollout of smart meters), end up in such an anti-climax? A review of the developments in the Netherlands clearly points out that the top-down style of policy making triggered part of the resistance. If the consumer and privacy organisations would have been involved from the outset, the upheaval could have been avoided. The two most important immediate causes that determined the anti-climax of the smart meter discussion in the Netherlands were:

1. Underestimating the sensitivity surrounding privacy aspects.

2. Disregarding the case for accompanying energy savings.

Both factors will be analysed more closely.

Underestimating the sensitivity surrounding privacy

In 2007, when the Dutch Government announced that all 7 million homes in the Netherlands were to be equipped with smart meters, it anticipated little resistance. After all, who would not welcome a device that could save both energy and money? However the Dutch national consumers' organization, Consumentenbond, considered that these intelligent monitoring devices, which transmit power-usage information to the utility as frequently as every 15 minutes, would make consumers vulnerable to thieves, annoying energy marketers and even utility and police investigations. Privacy campaigners joined in and spoke out strongly against this mandated surveillance technology, reviling the smart meters as 'espionage meters'.

A critical moment was the release of a report by the University of Tilburg [3], commissioned by the Dutch Consumentenbond, to test the privacy issues of the proposed smart meter bill to the conditions of the European Convention on Human Rights (ECHR). Article 8.2 of this Convention grants a legitimate breach of privacy in accordance with the law, necessary in a democratic society, and in the interest of national security, public safety or the economic well-being of the country, for the prevention of disorder or crime, for the protection of health or morals, or for the protection of the rights and freedoms of others. The main observations of this report were:

1. A legal basis for smart metering regulation following the EU Directive 2006/32/EC was in itself in accordance with this Convention, because its objectives of energy efficiency and functioning of the energy market are in the interest of the economic well-being of the country.

2. However, in the Dutch case, the mandated rollout was unconvincingly explained as a necessary measure in a democratic society in terms of pressing social needs, the actual providing of these needs and the principles of proportionality and subsidiarity. Questions like 'does smart metering really result in energy savings?' and 'does the goal to improve the functioning of the energy market constitute a 'pressing social need?' were not well addressed.

3. Furthermore, the minimum functional requirements of distance read out of consumed energy at very short interval periods (every hour for gas and every 15 minutes for electricity) and remote (dis)connection of capacity do <u>not</u> follow from the ESD-Directive and are disproportionate in the view of privacy and security. In the view of privacy, the registration of data regarding energy consumption reveals life patterns and the presence and absence of people in a house. In the view of security, the use of wireless networks is risky and hacking into a network is not inconceivable.

Overall, the report concluded that the mandatory nature of the proposed bill as well as the envisioned minimum functionalities of the smart meter, violate the right to privacy and are inadmissible on the basis of Article 8.2 of the European Convention on Human Rights. Removing the clause on the mandatory nature of the rollout alone does not take away privacy infringements caused by generating and transmitting detailed data on energy consumption. Even though functionalities as (dis)connecting from a distance and functionalities to spot fraud might be valid, without proper motivation, the necessity in a democratic society could not be sustained. Furthermore, in-depth research is necessary into less intrusive alternatives that on the one hand are able to achieve energy efficiency and a good functioning of the energy market, while on the other hand respecting the right to privacy and guarantee security.

Disregarding the case for energy services

Less well known compared to the privacy 'battle' but equally decisive, was the equivocal position of the government towards the energy saving benefits of smart metering. On the one hand the government considered the expectations of substantial energy savings to be the main rationale for a mandated rollout of smart meters. On the other hand the government was reluctant to put regulation in place for accompanying energy saving instruments, stating it is the responsibility of the market to introduce appropriate services.

In response to this seemingly contradictory approach, consumers' organizations as well as politicians stated that a residential smart meter alone does not automatically mean successful consumer involvement either in general or with energy savings in particular. To put it more strongly, the Lower House and Senate critized the lack of proof that a smart meter will actually lead to substantial energy savings. During the parliamentary debates, experts stressed the importance of additional automation technologies 'beyond the meter' [1]. Without easy accessible and convenient in-home energy feedback services, such as intuitive, aesthetic and affordable in-house displays and customized applications on web pages or cell phone, smart metering will not involve consumers and encourage mass market energy conservation.

Analyzing the causes and regaining public support

The Dutch Government and network operators underestimated the privacy objections for too long a period as 'much ado about nothing'. Their opinion was that there is simply not much intelligence to be gleaned from 15-minute-interval meter data. There is far more reason to worry about losing control of mobile phone use or whenever a consumer swipes his credit card at the local supermarket than when his smart meter reports the use of another kilowatt-hour. In the meantime, the public image of the smart meter could develop into a 'espionage meter', collecting sensitive information about the consumer's habits (i.e. when someone leaves the house or returns) and insights into a family's living patterns and relationships "which can affect people's freedom to do as they please in the confines of their homes".

In addition to the privacy discussion, the government's ambivalent position on the energy saving potential of the smart meter also weakened the law proposal. To ensure the support for the smart meter bill, the government was forced to announce the introduction of a trial period of at least two years ahead of a large-scale rollout. During this initial rollout period (in which smart meters will only be installed in new construction, renovations and large-scale redevelopment projects), the actual energy saving effects will be extensively monitored. Until the large scale rollout decision, expected by the end of 2013, the energy saving effects of the smart meter will be subject to reconsideration.

Evaluating the causes of the dramatic setback in the Dutch Senate in 2009, Dutch law makers and network operators decided to switch to a more cooperative approach in the build-up to resubmitting a compromise law proposal. While preparing the amended smart metering bill, the 'learning's' described above were now designated as key, and privacy, security, and energy saving were utilised as starting points for revised regulation and system design.

The most important step in the effort of regaining public support and ensuring more promising prospects for energy savings was the establishment of a series of round table meetings. All relevant (societal) stakeholders, including consumers' organisations and privacy experts, developed by mutual agreement the basic conditions for a favourable smart meter rollout and effective energy saving feedback. All stakeholders now work together in defining the essentials for revised system architecture that takes security and privacy and energy saving as design starting points. In the end, this consultation process laid the unanimously supported foundation for a compromise law proposal.

Compromise law proposal

The new Dutch law proposal offers consumers a legal choice in accepting a smart meter, ranging from having no smart meter at all to a smart meter with full functionality that provides a constant stream of data to service providers. Furthermore, the data from the smart meter will only be used for specific regulated purposes and/or only for services for which the customer has given its consent. Additional regulation will set out what measurement data these parties need in order to provide the customer with the information. It is important to distinguish between a minimum level of consumption data for bimonthly cost statements and billing and consumption data at a lower aggregate level for additional energy services. When accepting a smart meter, the customer will be obliged to authorise the network operator to use the minimum requisite level of consumption data. The customer will also have to explicitly give commercial service providers their consent before the service provider can use any other measurement data beyond the minimum regulated level. The customer therefore determines in advance by contract which measurement data generated by the smart meter is to be used by which party. To be able to access the measurement data, the grid operator will set up authorisation and authentication procedures. These procedures must ensure that individual measurement data is only used for the specific purposes for which the customer has given its consent [2].

Conclusions and learning's

The occurrences in the rollout of Dutch smart metering highlight the importance of a well-considered regulatory introduction of smart meters. The intense opposition from consumers' organizations and privacy watchdog groups showed the risk of underestimating the sensitivity for privacy aspects and disregarding the case for accompanying energy savings. The political setback meant that Dutch law makers and network operators had to switch from a top-down approach to collaboration with relevant societal stakeholders for a more acceptable policy, taking into account better the needs of – and potential risks for – end-users. This interactive policy making & learning approach resulted in broad support by stakeholders as well as consumers organizations, while offering more freedom of choice for consumers and more facilities for direct energy feedback. The most significant outcome of this new approach was the mutual intention to work together in designing the communication to accompany the voluntary roll out of the smart meters. This marks the real change in the troubled relationship between the government and distribution system operators on the one hand and consumers' organizations and privacy campaigners on the other hand.

The Dutch experiences elaborated in this paper are relevant for stakeholders from other Member States who also face growing public reluctance to the imposition of smart meters. An important learning in this respect is that an (enforced) legal choice for a voluntary rollout does not automatically mean a less effective outcome and a missed opportunity for a widespread smart metering penetration and promising energy savings. On the contrary, today the revised smart metering legislation, offering more freedom of choice for consumers and more functionalities for direct energy feedback, will be broadly supported by network operators, energy retailers as well as consumers' organizations. Within such a framework, smart meters could possibly contribute just as much to increasing energy efficiency than in the case of a mandated rollout.

The most important lesson from this, however, is that smart metering can only contribute to increasing energy efficiency, if the smart meters come both public accepted and in line with innovative smart metering services. Without meeting these preconditions, energy efficiency prospects from both mandated or voluntary rollout will be much more uncertain. These lessons the Dutch Government has learned the hard way should inspire other countries to anticipate and avoid similar (political) setbacks, which in the end may endanger the success of the EU-ESD and the EU-target of at least 80% of consumers equipped with a smart meter by 2020.

References

[1] Johan Boekema and George Huitema, 'Belemmering innovatie in energiemarkt door implementatie voorgestelde 'slimme meter' ' (Obstruction of innovation in the energy market as a result of the implementation of the proposed 'smart meter'), TNO Groningen, October 2008.

[2] Johan Boekema, 'Beoordeling uitvoeringsregelingen Slimme Meter' (Evaluation of Smart Meter implementation arrangement), TNO report, November 2010.

[3] Colette Cuijpers and Bert-Jaap Koops, 'Het wetsvoorstel 'slimme meters': een privacytoets op basis van art. 8 EVRM' (The 'smart meters' legislative proposal: a privacy evaluation based on Art. 8 of the European Convention on Human Rights), University of Tilburg, October 2008.

[4] SmartRegions, 'European Smart Metering Landscape Report', a comprehensive report on the developments of smart metering and metering services in Europe, SmartRegions, 1st edition, February 2011.

Energy Consumption Advisor (ECA) product: for a better use of electricity in households

Frédéric Klopfert,
Quentin Jossen

Université libre de Bruxelles, BEAMS Energy

Abstract

Sufficient energy savings cannot be achieved by solely promoting energy efficiency alone. Despite increased efficiency of individual products thanks to technological innovations, residential energy consumption is continuously increasing in Europe. Besides energy efficiency, mainly focused on technology and on continuous replacement of existing equipments by more efficient ones, important energy savings can and should be obtained through changes in user behaviour and user comprehension of energy.

To do so, sufficient and meaningful information should be provided to end-users, in a format that is adapted to the variety of their cultural and technical backgrounds.

The Energy Consumption Advisor (ECA) project aims at helping users understanding and reducing their consumption by giving them targeted information, not just displaying figures and graphs. It will indentify usage patterns, detects the major consumptions sinks in the household and, more importantly, indicate which energy practices should be amended in order to obtain significant energy savings.

The ECA product is basically an electric power metering device. It consists of an acquisition/processing box installed close to the main electric meter. Relevant data is transmitted to the identification/advisor server responsible for providing the users with personalised advices.

By using event-detection algorithms on the total household withdrawn current, switching on or off of any electric device in the house are detected. Further analysis on the transient and steady-state signatures of the device (harmonics, phase, I-U figure, etc) provides information to achieve a first level of unsupervised classification. However, at this stage, complete identification of each appliance is not possible. Time-based information, mainly sequences, cycles and time-of-use are used to fine-tune the identification.

The paper describes the methodology and techniques used for identifying appliance usage from a centralised measurement point and the results achieved so far.

Energy savings, a global approach

The increasing energy use is a major issue for most countries in the world for many different reasons: energy cost, climate change, fossil resource usage, sustainability, pollution etc. For Europe the increasing energy dependence on fossil fuels also constitutes a major long term threat for both geopolitical and economical reasons. Unsurprisingly, the European Union has reacted by promoting renewable energies and energy savings. However, looking in detail into the Directives, one can notice that they are mainly targeting at improving energy efficiency in the industry, transport and household sectors.

In Europe, households' final energy consumption has increased by about 8% between 1990 and 2007 [1]. Energy efficiency of domestic appliances has also increased during this same period but users have more than compensated the corresponding savings with new consumption practices. This can partly be explained by the fact that households generally do not have a good perception of their energy consumption and cannot clearly relate their practices to energy usage.

Arrow 1 of Fig. 1 illustrates that users, through their behaviours require a number of services (heat, hot water, leisure, cooking, refrigeration, laundry, etc.) that are performed by a number of appliances that consume energy (arrow 2). Although energy efficient appliances will achieve the same service with less energy, focusing only on this aspect "is a form for technology optimism: deep reductions in energy use will be achieved as new and more efficient technologies march into homes" [2].

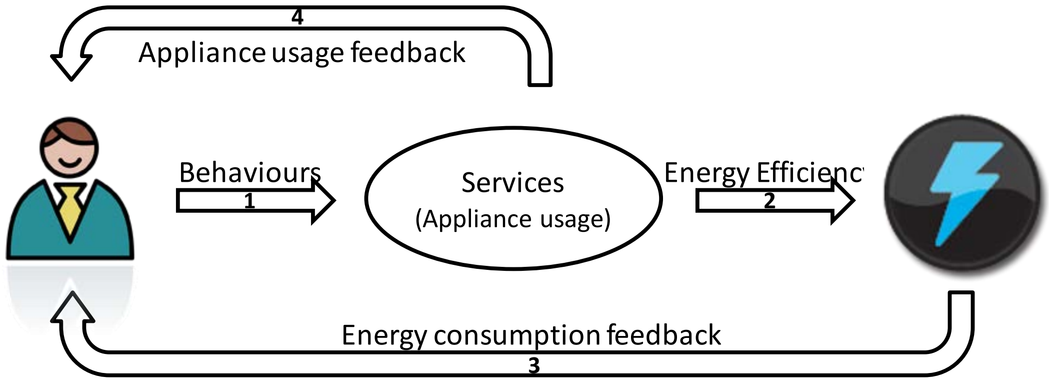


Figure 1: Interactions between users and energy usage

To increase users' awareness, tools and services have been developed to provide ***energy consumption feedback*** (arrow 3), such as energy meters, detailed energy bills, etc. Smart meters speed up the feedback rate, but are generally not designed to specifically instruct users on how to reduce their energy consumption [3]. A common characteristic to most tools on the market is that they rely on the fact that users have or will develop the necessary technical skills to progressively understand the relations among behaviours, appliance usage and energy consumption.

The Energy Consumption Advisor (ECA) product aims at providing, in addition to energy consumption feedback (arrow 3), adequate ***appliance usage feedback*** (arrow 4). It can help users locate some excessive appliance usage (television, lightning, etc.) and some energy wastes, such as those related to out-of-date appliances, stand-by consumption, badly maintained equipments or excessive energy consumption related to some practices, etc.

A special attention is given to user motivations and user skills. The way the information is provided to the user (display, messaging, media, format, etc.) is adapted to the user's profile.

This paper describes how appliance usage feedback can be achieved for electric appliances from a technical point of view. It is articulated as follows. The first section (background) exposes the positions of some key actors in this domain. Next our view of meaningful feedback is described. Sections three and four cover the methods used for evaluating appliance usage from a central measurement point and the system dynamics related to the learning process. Finally, just before the final conclusion, a brief discussion gives some perspectives and critics on the methodology.

Background

EU Directives on Energy Efficiency and Energy Market organisation have created favourable conditions for the development of Smart Meters. ***The metering industry*** has identified this opportunity and developed many different meters, to be used either by the electricity distribution operators (typically smart meters) or by households locally in-house. Some advanced meters also feature appliance switching automation (demand-response). However, most of these devices remain very technical and are limited to providing only energy consumption feedback (Fig.1), either on the global household consumption or on some predefined appliances (sub-metering).

The most recent European Directives related to energy savings[1], show that ***policy makers*** are mainly focussing only on the energy efficiency aspect. Targets are set for energy efficiency, renewable energy, etc, but no binding targets are set for energy savings as a whole. Policies and measures that specifically aim at changing user behaviours remain at national level.

However, the interest in changing user energy practices clearly exists and many ***academics* or energy agencies** have issued multiple studies and surveys on the energy savings obtained through direct and indirect feedback (such as Darby [4]) and on how to analyse the parameters to take into account for the design of feedback devices (such as Wood [5], [6] and Fischer [7]).

These studies are implicitly based on the attitude-behaviour-choice theories[2], whereas energy savings will be the result of humans making rational decisions provided they have access to relevant information and have the necessary knowledge. Other behavioural frameworks, such as social practices developed by Shove [8], provide an innovative and promising approach for taking into account the societal evolution, such as the increasing offer of new energy consuming devices.

Meaningful feedback for the user

Typical energy feedback systems provide figures or graphs that indicate a number of parameters such as the total energy consumption for a given period, comparisons with previous periods, instant power consumption, arguing that users will progressively learn how to adapt their energy consumption. This implicitly supposes that users are motivated in achieving energy savings, either for financial or for environmental reasons and are ready to make the necessary effort and have the knowledge to do so.

Darby [4] showed that a good direct feedback can help saving up to 5-15% but the persistence of such savings remains an issue. Our assumption is that these basic feedback systems require too much effort for most people. Users are not willing to change their habits if it is perceived as a loss of comfort or if the required effort is too important. However, they are ready to make some efforts if they can reduce ***energy wastes*** that are not perceived as loss of comfort. Some possible examples are standby consumption, invisible consuming devices, lights forgotten, etc.

Categorisation of energy wastes

In previous researches, we have classified these energy wastes into three categories, the first two being mainly technical wastes, while the latter is essentially behavioural:

- Performance waste relates to the fact that an appliance is consuming more than a “best available technology”. These wastes are related to energy efficiency and increase each time better products are put on the market, as the latter become the new reference. This waste can only be avoided by replacing the appliance.
- Maintenance. Some devices, such as freezers, air conditioning systems or dryers need to be correctly maintained by removing the frost or cleaning filters. Not doing so results in a temporally loss of performance.
- Energy practices, which include all conscious actions or internalized routines that make use of energy. They are closely related to social practices, social norms and representation of comfort.

---

1 Directives on energy performance of buildings (2002/91/CE and 2010/31/CE), energy efficiency (2006/32/CE), ecodesign requirements for energy-using products (2005/32/CE), internal market in electricity (2009/72/CE), labelling and standard product information of the consumption of energy (2010/30/CE)

2 ABC theories, such as Ajzen’s « Theory of Planned Behavior » (1991) and Triandis « Theory of Interpersonal Behavior (1977, 1980) try to integrate the complexity of understanding behaviour within a linear causality paradigm.

The distinction is important because the actions to be carried out by the users are different for each category. Performance wastes must be corrected by replacing appliances. The barrier is financial, but the effort is low. Maintenance wastes mainly require some cleaning work with low investments. The energy practice wastes require habit changes. Communication must be adapted for each category.

Need for disaggregated energy consumption

In order to determine the waste category, quantify these wastes and evaluate the energy savings potential, ECA requires the complete ***disaggregated energy consumption*** of the household, i.e. the precise usage of all appliances. From this information, it is possible to identify some waste patterns and provide adapted feedback to the user.

Two different methods can be used to obtain such information: sub-metering or software disaggregation. Sub-metering consists in installing separate meters for each energy-consuming appliance; data is then centralised for further processing. Software disaggregation uses statistical and/or signal processing software to identify individual appliance consumption within the total consumption measured at one unique central point, such as the main energy meter. This technique is also called Non-Intrusive Appliance Load Monitoring (NIALM) (see [9]). NIALM is complex and generally requires a manual setup (MS-NIALM) i.e. a learning phase during which users will need to turn each appliance on and off separately. Automated or automatic-setup monitoring (AS-NIALM) is also possible, though more complex to implement.

As we believe that feedback systems must be as easy as possible for the users, we have opted for an Automatic Setup Non-Intrusive Appliance Load Monitoring (AS-NIALM). This avoids putting additional burden on the user during the setup phase, but also each time new devices are installed within the household.

The two main issues with AS-NIALM are the disaggregation of the individual electric load (e.g. appliances) from a centralised measurement point and the system dynamics (e.g. learning process) of these algorithms. The two next sections describe disaggregation process and the system dynamics.

Disaggregation process

Fig. 2 represents the six elementary steps needed to achieve the complete disaggregation process.

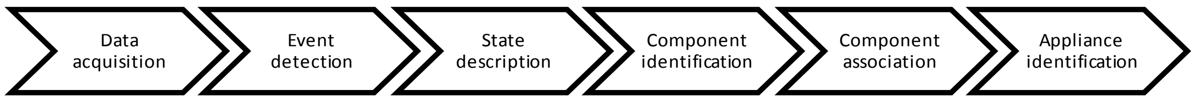


Figure 2: Disaggregation process

After acquiring data of the voltage and the absorbed current (***data acquisition***), a very critical step is to detect significant changes in the electricity consumption pattern. The detected changes are called events (***event detection***). Events are typically linked to the switching (on, off or mode change) of a specific component of an appliance, such as an electric motor, a resistor, etc.

To identify each component, we first need to build a good description (***state description***) of both transient state (typically when the component is switched on) and the steady state (when power consumption is stabilised or varies slowly). The beginning of the transient states corresponds to the moment where the active power and the wave form of the current change rapidly. Once power and current are stabilised, the transient state is ended and a steady state begins until the next event.

Component identification is achieved through classification of the transient and steady states described with discriminating features. For multi-components machines such as a washing machine, the knowledge of the switching on and off of components does not allow a direct identification of the corresponding appliance. An additional ***component association*** phase is necessary before the final appliance identification can be achieved.

Finally, the ***appliance identification*** can be deducted from the above information and some time-based information such as sequences, cycles and time-of-use.

The six steps of the disaggregation process are described hereafter. We focus on describing their function and the mathematical tools required for their implementation. Up to the section devoted to the identification of components, results illustrate the proposed development. The content of the two last sections is currently under study. Consequently, in these sections, the focus will be on the description of our strategy and the methodologies available in the literature.

Data acquisition

The system is developed on field data; we estimate that elaborating algorithms on simulated data does not allow understanding the problem and could lead to unrealistic treatments. Therefore, the first task is the acquisition of the data. In this section, we first explain why the data are acquired at appliance level in the development phase. Second, the considered appliances are listed. Finally the measurement parameters are specified.

Appliance level measurements

The current is measured considering one appliance at a time because the knowledge of what happens in the signal, namely a supervision signal[3], is required for development and validation purposes. Although our project aims at disaggregating the current drawn at the electrical panel level, which is the sum of the currents consumed by all the loads, it is difficult to build supervision for validating the algorithms. In order to quantify the performances of the algorithms, this supervision should be available and close to the reality. To build such supervision, a laboratory with advanced metering has been installed in our laboratory. It allows the acquisition of supervision signals while measuring the total consumption of an in-laboratory apartment. However, the global consumption has already been measured and will be processed in the future to test our works.

A running appliance is nevertheless a system with several electrical components, as will be developed later. Consequently, it already comes to the analysis of an aggregated consumption, namely the consumptions of the constituting components. The results should then be easily extended to the analysis of a house global consumption.

Type of appliances considered

The measurements have been performed in three households and our laboratory. High power appliances such as washing machine and clothes dryer have been considered. They contain mainly motors and resistors. Their cycling behaviour allows dealing immediately with a small scale aggregated consumption, as already mentioned. The consumption of electronic appliances such as television, computer, DVD player, etc. has also been taken into account. This set of appliances is considered sufficiently representative for development purpose and to illustrate the results achieved so far.

Measurement parameters

The data recorded are the grid voltage and the current consumed by the appliance. They are acquired with a 1600Hz sampling frequency on a 16-bits analog-to-digital converter. The single phase has only been considered up to now. The results will be later extended to the tri phase's case.

Event detection

The available data are the electric current and voltage. After the filtering for acquisition purpose, the first treatment they undergo is the event detection. The event detector aims at detecting electric component mode change. It cuts the signal in two types of states: the steady and the transient states. It follows that a steady state corresponds to no electrical component switching in the set of components consuming the current; continuous variations of drawn power can occur within this steady state. Accordingly, a transient state corresponds to a component being switched on or off.

This detection problem is divided into two steps: the first step is the amplification of the switch changes which consists in generating the signal to be monitored by the detection functions. This

---

[3] In this context the supervision consists in the monitoring of all individual components of an appliance. This enable automated validation, evaluation and quantification of the disaggregation algorithms.

signal will be called 'residual'; it should have high amplitudes when changes occur and low amplitudes in the other case, as illustrated in Figure 3-c. Thus, in this first step, the rough measurements are filtered and the output, namely the residual, is given to the second step of the global filtering function. This second step is the design of decision rules for detection purpose. When receiving the residual with its amplitude reflecting the possibility of component switching, the algorithm has to decide whether or not a change has occurred. The binary output is then set to one or to zero accordingly; it will be called detection signal.

The two steps are successively described in the next paragraphs. As proposed, we focus on describing the methods chosen to perform the desired function. The interested reader is referred to [10] and [11] for deeper details and equations.

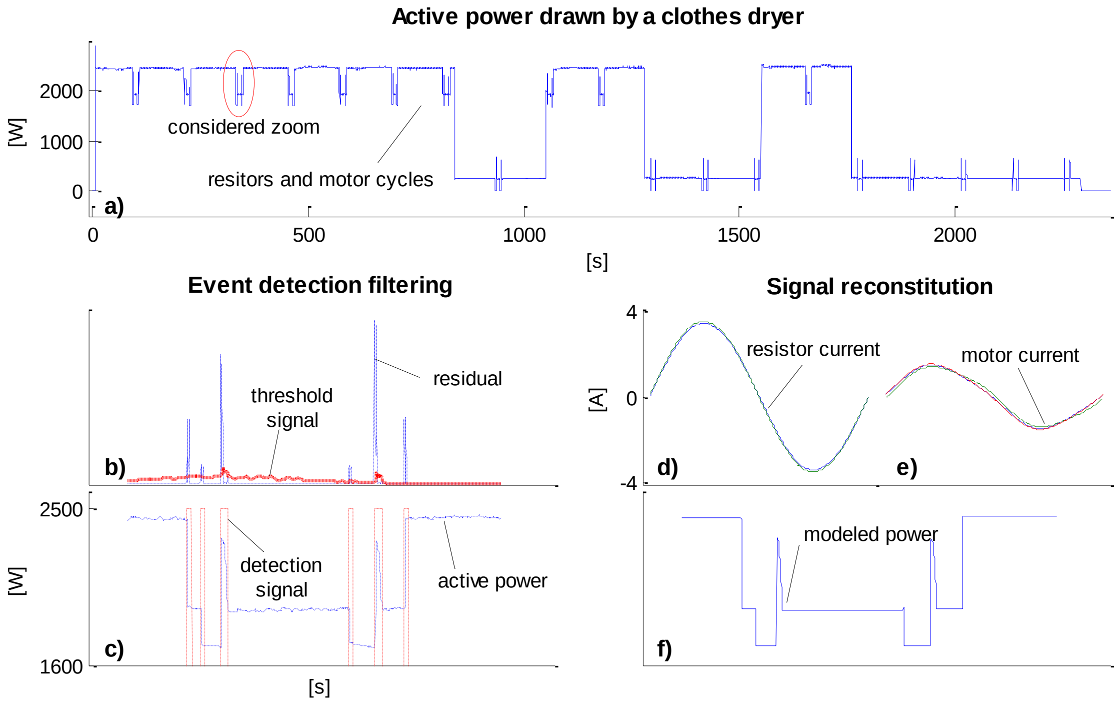


Figure 3 – a) The active power drawn by a dryer constists of cycles of on and off switching's of motors and resistors. b) To detect the switching's, there are amplified and thresholded. The threshold signal is a multiple of the local background noise. c) A transient state is associated to each over threshold value. The detection signal is set to 1. d) and e) The current drawn by the switched component is reconstructed by using the spectral content of states before and after the transition. f) The signal can be modeled by using first order and second order functions.

Amplifying the switching's

In order to amplify the switching's, the signal is filtered out. Two different filters have been designed. The first filter uses the active power variations to detect the switching of components. In order to detect changes in the power, a model of the signal can be used to predict the value of the next samples from the previous ones. The gap between the prediction and the observation is quantified. This gap would be an image of the change that occurred. This idea leads to the use of a Kalman filter. This filter allows the calculation of the proposed gap. Additionally, thanks to the adaptive nature of this filter, the model is updated according to the observations. A generalized likelihood ratio algorithm is then applied on the gap output by the Kalman filter. It computes the likelihood of having a change by using the stochastic distribution of the gap. This likelihood ratio is considered as residual.

The active power contains information on the amplitude and the phase of the current that is absorbed by the component. Nevertheless, components such as motors or devices with an electronic power supply could draw a variable power when they undergo a variable load. However, the physical devices responsible for the consumed current are unchanged. The shape of the current waveform would then be more representative of the running component than its amplitude. These considerations mean that, even for a fixed set of components drawing the power, variations in this power can occur. In order to cope with those fluctuations, we propose to look at the waveform of the current drawn by the loads. The proposed strategy is as follows. The waveforms are normalized with respect to their amplitude; then, the shapes of the two waveforms the amplitude of which equals 1 are compared by computing the squared difference, sample by sample.

Both methods allow building the desired residual; it is plotted in Figure 3-c. The choice will be done when analysing data from total aggregated consumptions. The algorithm using this residual to detect the switching is developed in the next section.

Detecting the switching's

At this stage, the residual to be treated has high amplitude when a component switching occurs and low amplitude when nothing happens. Rules must be defined to decide, at each time, whether the detection function outputs 0 or 1.

A thresholding rule is defined to decide whether or not switching occur. The threshold is automatically computed according to the background noise of the signal, instead of choosing a fixed predefined value. We have then to define this background noise and how to use it in order to compute the threshold.

The background noise is computed on a sliding 200 ms window. It is defined as the mean value of the 40^{th} percentile in that window. Doing so, the high amplitude samples do not bias the background noise evaluation. The algorithm searches for the multiple of the background noise that leads to a stable number of over threshold samples. As a result, a thresholding signal is built as a multiple of the local background noise. This signal is plotted in Figure 3-c, along with the residual.

State description

The signal has been divided into transient and steady states. Both types of states must now be mathematically described in order to perform the identification later in the process. Their description is explained separately as they are based on quite different approaches. In both cases, features have to be found, that allow discerning one electric component from another. These features are described, as well as their calculation and the method used to validate their choice.

Steady states

The active and reactive powers are used, as it is done since the first work in the field [12]. However these powers can be varying when no changes occur in the set of components; the power of the motor of a washing machine varies according to the load torque; the power of the television varies according to the displayed screen. Consequently, clusters could overlap and other features should be used avoid it. The spectral properties are used: harmonic magnitude normalised with respect to the fundamental's amplitude, total harmonic distortion. As regards Shannon's theorem, harmonics until 350Hz can be considered as the sampling frequency is 1600Hz. Parameters describing the shape of the current waveform are also used. As proposed by [13], we use the ratio of the maximal amplitude of the current and its mean value to describe the shape; and time evolution features such as the time between the zero voltage and the maximum value of the current.

The features are considered to be well selected if they lead to separated clusters in the features space. Such features space is represented in Figure 4 where resistors, motors and electronics have been considered. If supervision is available, the validation of the features choice can be based on the confusion matrix[4] of a supervised classification. Actually, this classification should operate well if the features are relevant.

The gross signal is the total current consumed. This reflects that one single appliance can be running several electric components. Consequently, the properties cannot be computed on the measured

[4] Confusion matrixes are used to evaluate a supervised classification. Columns represent the predicted classes, while rows represent the expected classes. A good classification will generate a diagonal confusion matrix.

current but should be extracted from the difference between the present state and the previous one. The features are then computed on a reconstructed signal as follows:

After reception of the time indexes of successive steady states, the difference in the spectral properties of both states is computed. The result is the spectrum of the signal drawn only by the new electric component; the latter can be reconstructed and the description is based on this new mathematical signal.

This reconstructed signal is plotted in Figure 3. Six transitions occur in the plot of Figure 3-b; Figure 3-d gives the reconstructed signals for the two events corresponding to a resistor switching and Figure 3-e gives the signals corresponding to the four motor switching. One can observe that both on and off transitions help describing the switched component.

Transient states

The transient states are either on or off switching. We focus on describing the on transitions; the off transitions mainly consist of down steps that do not contain lots of information, as it can be seen in Figure 3-b.

When looking at a consumption curve, one can observe that transient states are reproductive shapes, even if sometimes complicated shapes. Therefore, the approach follows the method proposed by [14]. First, the signal within the transient state is decomposed in primitive functions. These functions describe the evolution of the signal; they are constant, growing or decreasing and can be first or second order functions. Second, a letter is associated to each primitive and the state is represented as a word. Other parameters such as the energy of the signal within the state, the ratio between maximum and mean power values or damping properties could also be use. This is currently under evaluation.

The features are computed from the shape of the active power. Therefore, no complicated calculation is required as is the steady state case. As regards the validation of the chosen features, it does not differ from the steady state case.

Component identification

The component identification is a common classification problem; objects have to be classified according to their features. The objects are the signal states and the features are the signal properties within these states, as described in the previous section. We aim at nonintrusive methods; therefore, unsupervised classification techniques have to be implemented. These methods attempt to identify clusters from the points in the features space, as illustrated in Figure 4.

The components are identified with a two steps classification strategy. The first step consists in clustering and classifying the components according to their nature. The second step classifies the components within their nature cluster; this is the component classification itself.

Complementary using steady and transient characteristics

The description of the steady and transient states is complementary. The steady state description as well as the description of an on transient state characterise the component that has been switched on. Two component identifications are run in parallel, each one considering the properties of one type of state. Their output can be contrasted in order to compute a reliability coefficient; this coefficient is high if the two outputs are similar, in the other case it gets a low value. This reliability concept is developed in a next section. In the two next subsections, we focus on the steady states characteristics as the transient states description is currently under study.

Identifying the component nature

Identifying the nature of the component is a classification problem with a predefined number of classes. Therefore, a K-means algorithm[5] has been chosen. It classifies the components according to their nature; there will be as much classes as defined component natures. Up to now, three types

---

[5] The k-means method is a clustering technique that partitions n observations into k clusters, where k is a predefined value.

have been imagined; they correspond to resistors, motors and electronic devices. Not all the features are relevant when looking only at the component nature. One can see in Figure 4 that using the THD[6] the ratio H3[7]/THD and the normalized H3 lead to clusters related to the component natures, even if some overlaps do occur.

Identifying the components within their nature

The second classification step is far different because the number of clusters to identify is unknown; we have no prior information about the number of appliances contained in a house. A sequential classification algorithm is used. Looking at the steady states, the components will differ by the magnitude of their consumption from others within a component nature cluster. As far as the transient state properties are concerned, two nearly identical but different components could have different transient shapes.

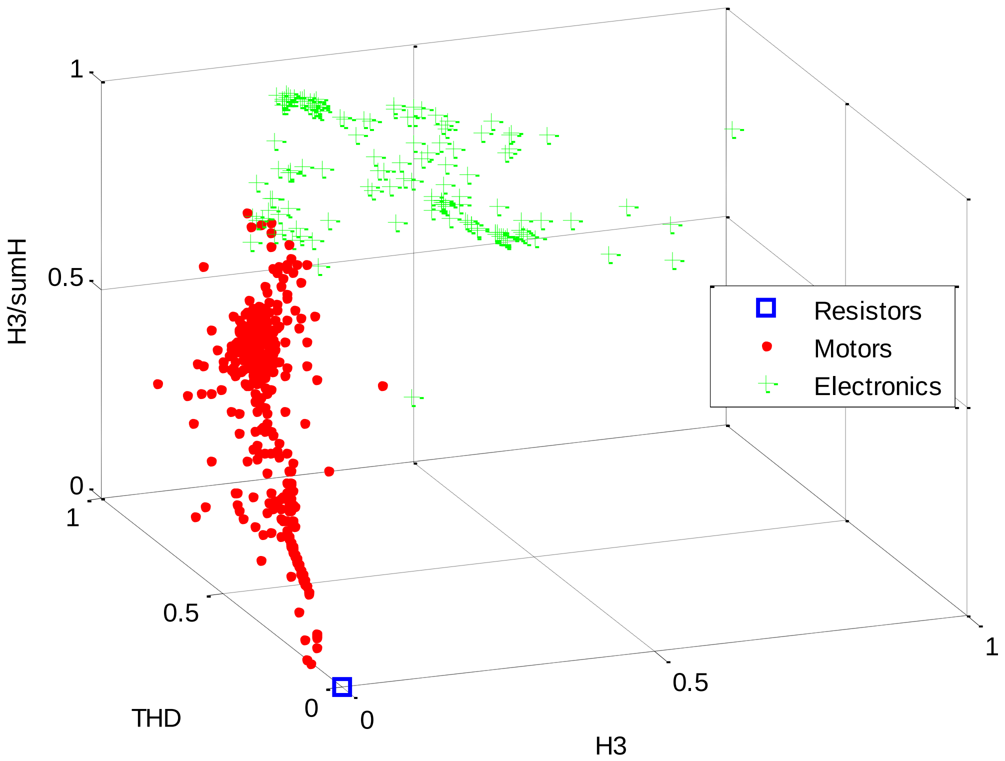


Figure 4 – The output of the component nature identification shows that using features not related to the amplitude of the drawn current allows clustering the states according to their nature, even if some overlaps do occur between motors and resistors. The features are normalized according to all the observation before being given to the K-means clustering algorithm. Furthermore, the harmonics are normalized with respect to the fundamental amplitude. Number of switching: 61 resistors, 597 motors and 148 electronic devices.

Component association

An appliance is considered as a system with one or several electrical components. The previous step, the component identification, outputs the components (nature and identifier) related to the on and off switching's detected. Therefore, components running together have to be identified as such from the time sequence of all the running components, as they may be running within the same appliance. For illustration purpose, let consider Figure 3–a where the active power of a dryer is plotted. When this dryer will be running, three components (A, B and C) should be identified: a 250W engine, a 1700W

---

6 Total harmonic distorsion
7 Third harmonic

resistor and a 500W resistor. Consequently, it should be detected that if A runs, then B and C runs within time T. This problem is developed by [15].

An appliance is then represented as a system of components whose sequences could vary and be described. This would have the advantage of being independent of the appliance program ran by the user. The nature and the sequence of the components identified as running together will help identifying the appliance. This is developed in the next section.

Appliance identification

The available information is twofold. First, the previous step outputs sets of components running together; the nature and an identifier are also available for each of the components. Second, generic information about the typical constitution of the main appliances has been collected; consequently, a generic database can be used to translate the components sets into running appliances.

Using such a generic database relies on the three following arguments. First, similar types of appliances of a house involve similar components with typical power ranges. That is all the washing machine and clothes dryers own an engine and some resistors; the fridges use an engine as compressor; the lights have resistor or electronic behaviour, etc. Works have been led to describe the constitution of residential appliances [16]. Second, the usage of the appliances can be generically described; the washing machine is used punctually whereas a fridge runs night and day with a cycling behaviour. Third, information on the time of use is valuable to help distinguishing different appliances using components with similar nature.

System dynamics

The functionalities to be achieved have been described, along with the mathematical tools used or to be used. The present section is devoted to the dynamic of the system when running. The arguments given here are projections, as the complete system is not yet operational. These arguments will guide the architecture of the system and consequently, they will impact the development of our algorithms.

Initialisation and run phases

When started, before producing outputs, the algorithm requires a minimum consistent set of data. The set of data is considered consistent if it contains the main appliances of the house. Therefore, a data collection period would be required, that is currently estimated between one and two weeks. After this period the analyzer could switch to run mode; the data are given to the classifiers that will analyse the data. However, the classification algorithms have to adapt their rules according to the new components that enter the consumption.

Using a house limited database

The recurrence of the events is valuable information. This stands for the components, for the sets of components and for the appliances identified; we use the term entity in these paragraphs. For example, when a set of components is identified as an appliance, this set could be stored in a database. Consequently, new information is built that could be used for later identifications.

The database has three levels: state, component and appliance. At the state level, steady and transient states are stored along with their features and time occurrence. At the component level, the nature and the identifier of the component corresponding to each of the state is recorded. Finally, at the appliance level, identified appliances are stored with the associated components, their sequences and the measured power characteristics. The time during which the data are conserved and decision rules for erasing unused data must still be defined.

Our aim is to limit the database to the house content for two reasons. First, it allows keeping the information within the house; thus limiting data transfer and hence avoiding privacy issues. Second, the development and maintenance costs for building a database with all existing appliances seem excessive; also, there are so many existing appliances that having an exhaustive database seems unrealistic. Nevertheless, some of today's actors already having such a database have chosen this strategy to develop their tool; their performances rely on the exhaustiveness of their database.

Discussion

The works being led to reach the disaggregation of the residential consumption has been exposed through this paper, along with the results achieved so far. In this section, we first argue the cost/performances trade-off; then we expose technical issues that have still to be solved.

Cost/performances trade-off

The proposed method aims at being less intrusive than the existing methods to our knowledge. According to us, this intrusiveness arises from the supervised learning that the user has to perform; supervised learning is a major disincentive or barrier to a general deployment of such a system. But, in order to be robust without the information given by the user, the approach we propose requires more detailed information than only the active and reactive powers. Consequently, the acquisition requirements are higher: 1600 points every second instead of 1 point every minute in some works. Thus, the production of such devices will necessarily be more expensive.

As regards the acquisition step, the quantification of the data is also of importance. The data has been acquired with a 16-bits analog-to-digital-converter, though the final ECA product is expected to run with a 12 bit resolution.

At a final stage, the algorithms should be implemented on a platform with limited resources. Therefore the computational burden should be as light as possible. Currently we aim at demonstrating the feasibility of our approach. In a future effort the calculation will be pruned in order to keep only the necessary operations and features.

Technical issues

A key point of our project is the distinction between the electrical components and the appliances. This allows identifying appliances independently of the selected program (e.g. washing machine). This also partially answers the problem of multi-states appliances pointed out by some works. However a strategy has to be defined to deal with variable power appliances. For a vacuum cleaner with four power modes, as an example, our algorithm would consider this as four different appliances. Because the event detector searches for abrupt changes in the consumption, appliances being progressively turned on cannot be detected. A longer time scale analysis should maybe be performed to accurately capture with these appliances.

Up to now, we have only been working with single phase appliances. Working with a three-phase and neutral configuration will not bring many new issues as the three phase currents are independent of each other. However three-phase configuration without neutral will require new algorithms to compensate the missing current.

Conclusions

Assuming that the consumer behaviour is part of the solution for reaching significant energy savings, we have come to the conclusion that a comprehensive and adapted energy consumption advice product is necessary for the household sector. This advice must be adapted to the consumer skills and motivations and must not be an additional burden for them.

For electricity consumption, our position is that an automated advice can be derived from the detailed knowledge of the consumptions of all loads within the household. The first phase of the “Energy Consumption Advisor” is therefore to disaggregate the total electricity consumption into individual load consumptions. From a technical viewpoint, residential consumption is the most complex situation as there is a very wide range of domestic appliances on the market.

Our approach is to analyse the drawn current and power using various signal processing techniques. This allows us to identify when components are switched on and off. By combining this information with generic appliance descriptions, time of use, sequence and pattern recognition, we expect to correctly identify most appliance usages.

The preliminary results seem to demonstrate the feasibility of this approach, even if a lot of research still has to be done. Satisfactory results have been obtained to identify component switching, component nature classification and component identification, only using the steady states features. Integration of the information provided by the analysis of the transient states and the sequence analysis are the next steps for implementing the component and appliance classification.

The Energy Consumption Advisor project is clearly at the intersection of technology and human sciences. This paper focused on the main technical challenge of disaggregating the total electricity consumption of a household into individual appliance consumption. Results regarding non-technological aspects, such as energy waste identification, user profiling, automated advice generation and advice communication will be covered by further papers.

Bibliography

[1] European Environmental Agency, 2010. Final energy consumption by sector (CSI 027/ENER 016) - Assessment published Sep 2010. Can be accessed: http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-1/final-energy-consumption-by-sector-5.

[2] H. Wilhite, “Will efficient technologies save the world? A call for new thinking on the ways that end-use technologies affect energy using practices”, eceee 2007 summer study – Saving energy – Just do it!, pp 23-29.

[3] F. Klopfert and G. Wallenborn, 2010. “Les compteurs intelligents sont-ils conçus pour économiser de l’énergie ?”, Terminal n° 106, pp 83-96

[4] S. Darby, 2006. “The effectiveness of feedback on energy consumption. A review for DEFRA of the literature on metering, billing and direct displays.” Environmental Change Institute, University of Oxford. Can be downloaded at: http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

[5] G. Wood and M. Newborough, “Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design,” Energy and Buildings, vol. 35, no. 8, pp. 821-841, Sep. 2003.

[6] G. Wood, M. Newborough, 2007. “Influencing user behaviour with energy information display systems for intelligent homes.” International Journal of Energy Research 31:56-78

[7] C. Fischer, “Feedback on household electricity consumption: a tool for saving energy?”, Energy Efficiency (2008), Volume: 1, Issue: 1, Publisher: Springer Netherlands, Pages: 79-104

[8] J. Ingram, E. Shove and M. Watson, 2007. Products and Practices: Selected Concepts from Science and Technology Studies and from Social Theories of Consumption and Practice.

[9] H. Najmeddine et al., “State of art on load monitoring methods,” in Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International, p. 1256-1258, 2008.

[10] M. Basseville, “Detecting changes in signals and systems - A survey,” Automatica, vol. 24, n° 3, p. 309-326, Mai. 1988.

[11] Q. Jossen, F. Klopfert and J.C. Maun, “Detecting changes in the residential electric consumption”, Power Systems Computation Conference (PSCC), Stockholm, Sweden, 2011 [submitted].

[12] G. Hart, “Nonintrusive appliance load monitoring,” Proceedings of the IEEE, vol. 80, n°. 12, p.1870-1891, 1992.

[13] M. Ito et al., “A method of appliance detection based on features of power waveform,” in Proceedings of the International Symposium on Applications and the Internet, p. 291-294, 2004.

[14] S. Charbonnier et al., “Trends extraction and analysis for complex system monitoring and decision support,” Engineering Applications of Artificial Intelligence, vol. 18, n°. 1, p. 21-36, Feb. 2005.

[15] G. Das et al., “Rule discovery from time series” in Proceedings of the 3rd international conference of knowledge discovery and data mining, pp 16–22. 1998

[16] R. Stamminger and al., “Synergy Potential of Smart Appliances.” Report of Smart-A project. 2008

Introducing in-home displays to households
Preliminary results from a Norwegian pilot study

Hanne Sæle and Silke van Dyken
SINTEF Energy Research

Abstract

This paper presents preliminary results from a pilot study for testing the use of in-home displays in about 50 Norwegian homes. The pilot study is part of a research project at SINTEF Energy Research focusing on the environmental benefits related to the full rollout of Smart Metering. The pilot presented in this paper will include three customer surveys and the testing of the newly developed Norwegian in-home display "e-Wave".

The paper gives an analysis of the first customer survey carried out in December 2010. Topics that will be discussed are:

- To what extend are customers aware of their energy consumption?
- What are the main reasons for saving energy (environmental concerns or financial benefits)?
- What expectations do customers have related to the installation of the in-home display (preferred display options, frequency of use etc.)

In addition, the test group was asked to provide basic demographical data. The first survey replies allow for a preliminary rating of customer habits and attitudes. This is supported by analysing the responses of a control group that answered the same survey.

The aim of this paper is to provide a preliminary rating on how and why customers are using electricity and how the consumption pattern can be changed to achieve a more efficient use of energy. The installation and testing of the in-home display as well as hourly metering data will support this process later in the project.

Introduction

EU has introduced binding targets for 2020 to reduce greenhouse gas (GHG) emissions by 20 %, ensure 20 % of renewable energy sources in the EU energy mix and reduce the EU global primary energy use by 20 % [1]. These targets have increased the focus on energy consumption of final customers. In April 2009, the European Parliament voted to support the rollout of Smart Metering within the European Union. The Electricity Directive requires full deployment by 2022 at the latest, with 80% of customers equipped with Smart Metering systems by 2020 [2].

The Norwegian electricity supply and consumption situation has been frequently discussed in recent years. The media is mostly concerned with steadily growing consumption, high electricity prices and planning of new overhead lines. Electrical space heating is common in Norway and the Norwegian household electricity consumption is far above European average [3]. The electricity generation in Norway comes mainly from hydro power. Thus, the water levels in reservoirs have a high impact on electricity production and prices. Customer concerns and intensive media discussion has been initiated due to high electricity prices caused by periods with very low temperatures during the two last winter terms and water levels in reservoirs below average.

More efficient consumption and customer awareness can be one possible solution to help the supply situation. The potential for saving energy is anticipated to be high due to the rather high portion of the household electricity consumption used for space and tab water heating.

The full implementation of Smart Metering in Norway was originally planned to be finished by 1st of January 2018. This deadline has been moved forward to the end of 2016. There are proposals for implementing Smart Meters in Central Norway even faster (2013), since the supply situation is highly strained mostly due to limited production and import capacity to this region [4].

The research project

As a consequence of the increased focus on energy consumption and the rollout of Smart Metering, a new research project has been established at SINTEF Energy Research: "Environmental benefits from full scale implementation of Smart Metering[1]" (2009-2013).

The focus in the project is

1. to contribute to increased efficiency of the data management related to full scale implementation of Smart Metering, and
2. to achieve environmental benefits in terms of reduced energy and power demand by making the customers more conscious regarding their own consumption. It will be investigated to what extend customer awareness can be increased by using load control and in-home displays.

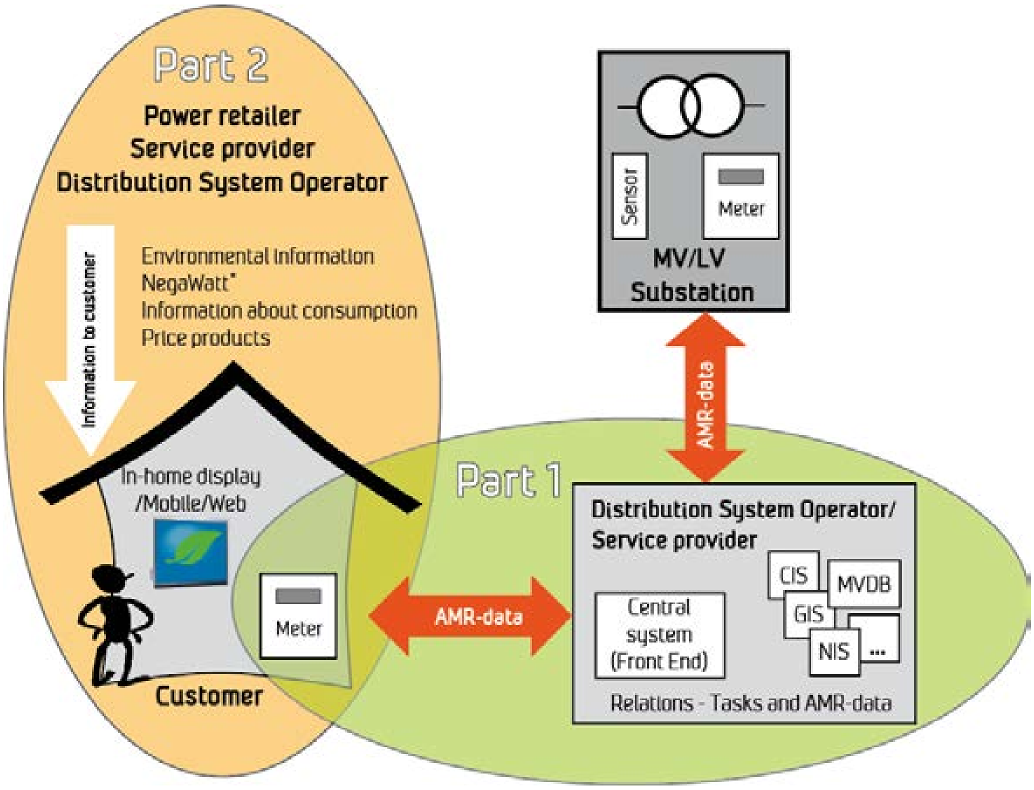


Figure 1 Technical focus in the two parts of the research project

The research project is funded by the Norwegian Research Council[2], Energy Norway[3], Enova[4], Norwegian DSOs and power retailers. This paper is based on the work performed within the second part of the research project, see Figure 1. Several pilot studies co-operation with different Distribution System Operators (DSOs) and power retailers are planned in the second part of the project.

Pilot studies

[1] www.sintef.no/m-ams (In Norwegian)
[2] The Research Council of Norway, http://www.forskningsradet.no/en/Home_page/1177315753906
[3] Energy Norway, Trade organisation, http://www.energinorge.no/english/
[4] ENOVA SF, http://www.enova.no/sitepageview.aspx?sitePageID=1346

Different types of technology (in-home displays and energy control systems), customer information (demand, energy efficiency, etc.) and different price incentives (hourly market price (Elspot)) will be included in the planned pilot studies. The objective is to identify how to increase the customers' awareness regarding their own electricity consumption, and thereby encourage them to reduce their consumption.

A literature review on customer feedback was carried out prior to the pilot study presented in this paper. In [5] and [6] studies with direct feedback, indirect feedback and feedback with time of use pricing are listed and study characteristics and results are summarised. In [5] it is indicated that the savings from direct feedback range from 5-15 %. One example of an ongoing study is the German feedback project "Intelliekon" [7]. In this study customer feedback in written form and a web-based presentation are tested. A British study [8] explores customer preferences for in-home energy display functionality. Experiences and recommendations from these pilots and other research projects have been considered in the scheduling of the pilot and the survey design.

In the first pilot study about 100 in-home displays will be installed at household customers (about 50 located in the Western part of Norway and about 50 located in the Eastern part of Norway). The newly developed Norwegian in-home display "eWave" will be tested.

Three customer surveys are planned to be conducted during a one-year test period. The first survey will be sent to the customers before the in-home display is installed, the second one about three month after the installation and the third one at the closure of the pilot study.

In this his paper, the results from the first survey performed at the customers located in the Western part of Norway (about 50 households) are presented.

In-home display "eWave"

The newly developed Norwegian in-home display "eWave" has different display options (e.g. graphs or speedometer) to present both electricity consumption (kWh) at different time intervals (real-time, hourly, daily, weekly, monthly, yearly) and energy costs (NOK). Figure 2 shows the system outline of the eWave in-home display.

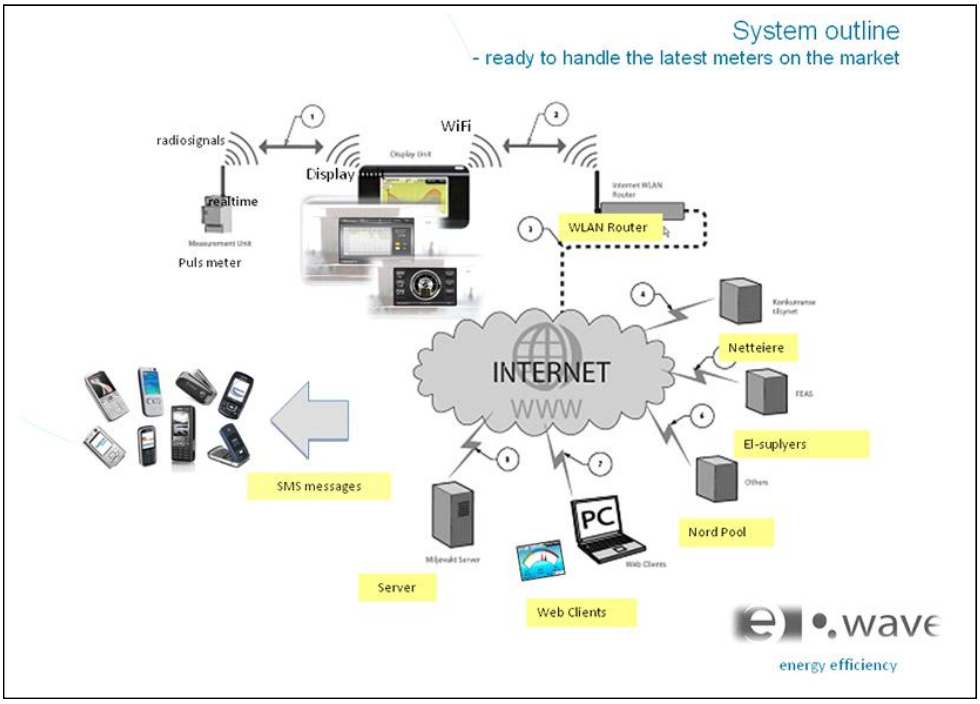


Figure 2 System outline – eWave

The electricity consumption can be shown in total but also for single circuits. The possibility of sending messages to the customers via the in-home display includes different options for customer information and motivation (e.g. comparison and competition). Another feature is the logging of customer activity on the display. More information can be found on http://www.ewave.no.

Customer surveys

In total, three surveys are planned during this first pilot study. The same structure might be used in the other pilot studies planned in the project dependent on the findings and knowledge obtained in the first pilot study. Some questions are to be included in all the surveys to be able to monitor and follow up changes in customer habits during the pilot study. The customer surveys are web-based and the participants are contacted by e-mail. The answers are treated anonymously.

The surveys contain questions concerning:

- Demographical data
    a. Building type, size and age
    b. Family size and age structure
    c. Income
    d. Heating device

- Electricity consumption
    a. Habits (appliances on/off)
    b. Attitudes (environment – economy)
    c. Energy savings
    d. Meter-reading and energy bill

- In-home display
    a. Motivation for participation and expectations
    b. Evaluation of the in-home display (design, user friendliness, etc.)
    c. Interesting functions
    d. Frequency of use
    e. Does the in-home display support changed focus regarding the use of electricity?

Based on the survey results, the project will try to group the households into three categories such as: environmentally aware, cost-conscious and conservative customers in order to provide general information on household characteristics.

Recruiting the household customers

The households participating in the pilot study are all customers of the power retailer Askøy Energi. An announcement of the pilot study was presented in the local newspaper and 47 customers volunteered for participation. One criterion for participation was an annual electricity consumption of at least 20.000 kWh to be sure that the heat demand fully or partially is covered by electrical space heating. Electrical space heating stands for approx. 63% of the electricity consumption in Norwegian households [3] and high saving potential is expected.

The customers perform self-reading of their meter every third month. Smart Metering will not be installed during the test period. The consumption data available in the test period will be the self-reading data and the data registered by the in-home display.

Since the customers participate in this pilot study through self-selection, it can be expected that they are more than average interested in and conscious about their own electricity consumption. The project will later discuss whether the results can be generalized and transferred to an “average” customer.

Survey Results

The first test group survey was finished in December 2010 with a very high response rate: 45 of 47 customers answered the questionnaire. This can be interpreted as a sign for the above-average customer interest in own electricity consumption and the in-home display pilot programme.

The test group households have an expected average energy demand of about 24.500 kWh per annum based on estimations from the power retailer. This number will be updated by metering data available later in the project.

The same survey, except the questions concerning the in-home display, was sent to a selection of volunteering household customers (reference group). Initially it was planned to establish a control groups with randomly chosen household customers of the same power retailer who did not volunteer for the pilot study. The reference group will be asked to answer the same survey except for the questions concerning the in-home display. For this paper a preliminary reference group was chosen, consisting of customers not located in the same area as the test group customers and supplied by other power retailers than Askøy Energi. This reference group allows for preliminary comparisons with the test group. The preliminary group will be replaced by randomly chosen customers supplied by the same power retailer as the test group customers later on in the project.

This work will be supported by establishing. These customers

The results for the reference group shown are based on 49 fully answered surveys. Based on customer information, the households in the reference group have an energy demand of about 18.700 kWh per annum on average.

Demographical data

A majority of the test group participants live in single-family homes (84 %). The other participants live in two-family houses (11 %) or in a row house (2 %). The mean age of the buildings is 29 years. The average living space is 185 m^2 per household. Altogether 154 people are living in the 45 participating test group households.

The kind of housing is more varied in the reference group. More than half of the reference group customers live in single-family or two-family houses (56 %). About 17 % live in a row house and about 27 % of the customers own or rent an apartment. The mean age of the buildings is 38 years. The average living space is 127 m^2 per household. All in all 147 people are living in the 49 reference group households.

Most households in the test group are families with three or more persons. The share of singles or couples without children is notably higher in the reference group. Figure 3 specifies the share of different types of household for both groups.

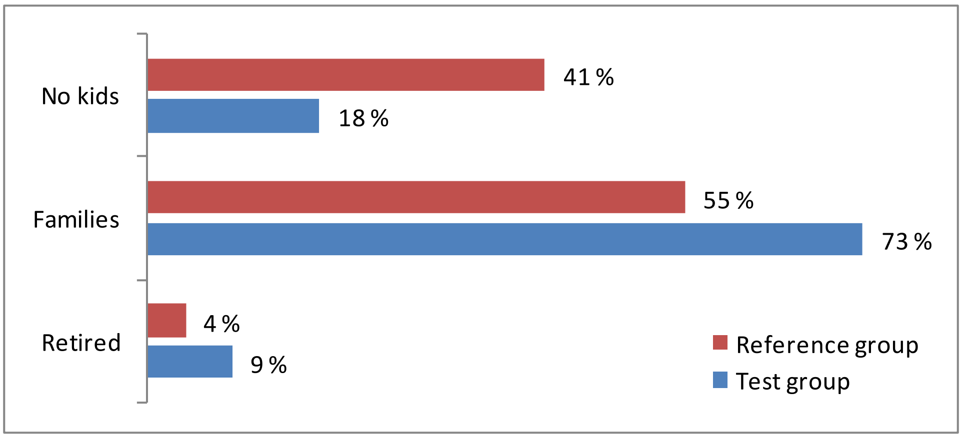


Figure 3 Types of household

Heating devices

A large majority of the households in both groups have a wood stove and/or electrical heater cables for space heating. About half of the households in the test group use a heat pump and/or electrical heaters. The share of heat pumps is lower in the reference group (about 20 %), but the share of electrical heaters is twice as large as in the test group. Only few households apply other heating systems. The allocation of heating devices is shown in Figure 4.

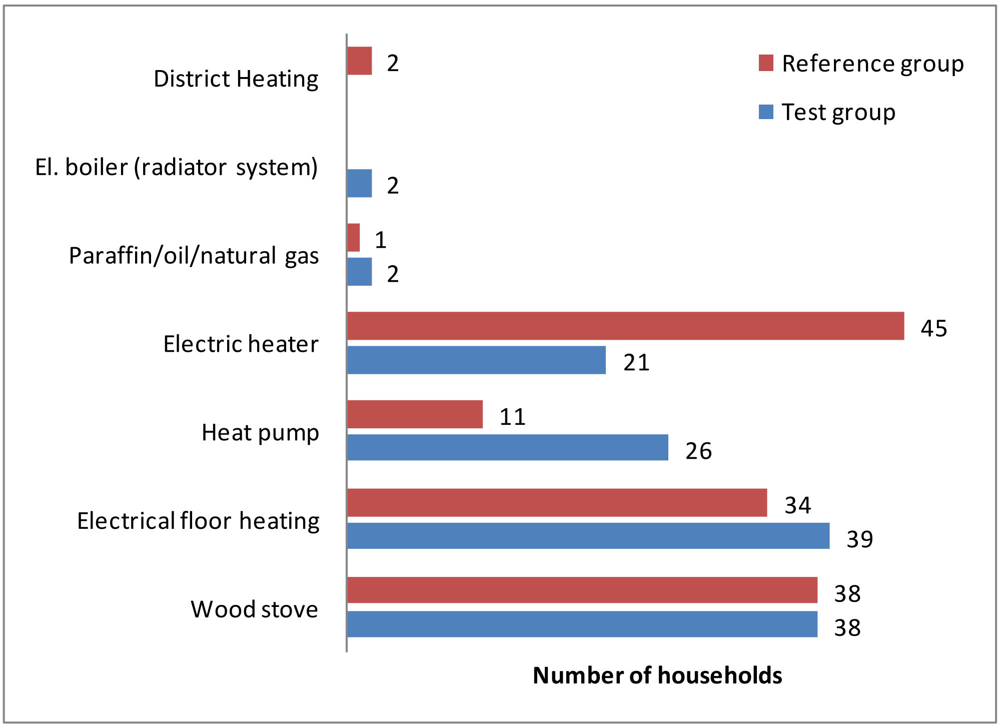


Figure 4 Household heating devices

The annual electricity consumption (kWh) is related to different variables as i.a. the number of persons in the household, living space, income and year of construction specified by the customers. The mean specific annual electricity consumption is 138 kWh/m^2 (Reference group: 151 kWh/m^2). The annual electricity consumption of one person is about 8.000 kWh/m^2 on average (Reference group: 6.660 kWh/m^2). Based on these numbers, a common trend can be shown in both groups: Households with four or more people are using less energy per capita than single-person households.

In neither of the two groups it can be found a clear relation between the annual consumption and the income nor the annual consumption and the year of construction.

In addition to the four parameters described above, the presence of any dependence between the annual specific electricity consumption per m^2 and the heat source mainly used has been analysed. By comparing test group households with and without a heat pump (26/21) it can be concluded that households applying a heat pump for space heating on average have a lower electricity consumption.

Electricity consumption – Habits and attitudes

All respondents were asked to estimate how much attention they pay to their own electricity consumption. The customers in both groups approximately have the same level of activity. The customers in the reference group read their meter more often than customers in the test group (customers are asked to read their meter every third month). All questions related to customer activities are shown in Figure 5.

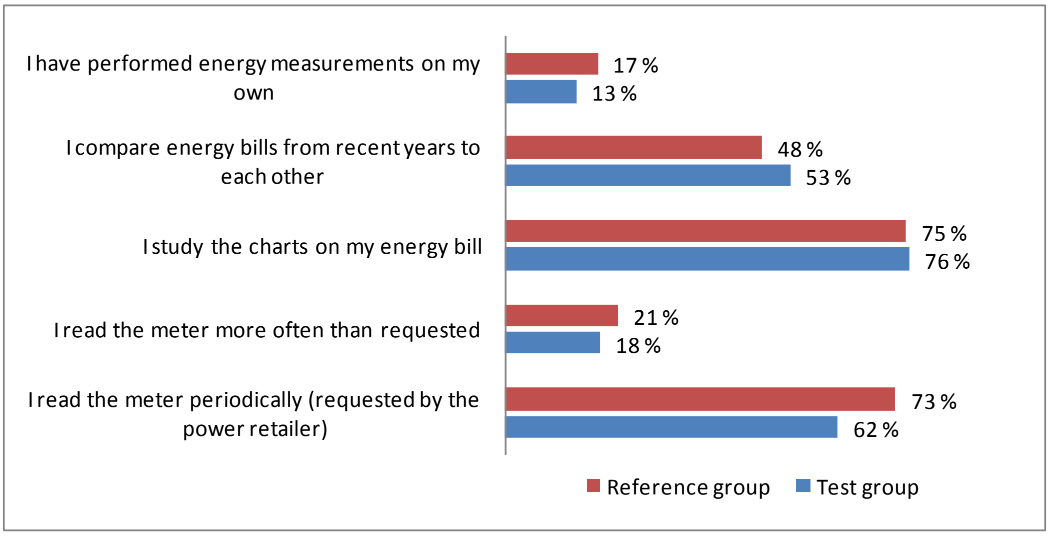


Figure 5 Activities related to own consumption

For household customers in Norway, the energy consumption for the actual and previous periods are presented on the energy bill as bar charts. A high share of customers in both groups (~75 %) study these consumption charts on their energy bill. This indicates that there is a special interest in more detailed and graphical consumption information for the household customers in general.

Next, the respondents were asked to range their own knowledge of how to save energy in their home. In the test group, 67 % meant they had good knowledge, 16 % ticked the “excellent” option and 18 % meant they had only limited knowledge. The customers in the reference group consider themselves to have a slightly better knowledge of how to save energy. Only 2 % ticked the “limited” option. The results are summarised in Figure 6.

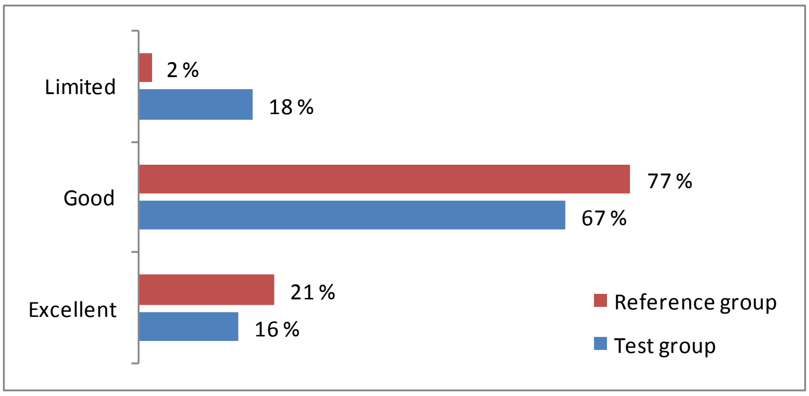


Figure 6 How do you range your knowledge of how to save energy?

The annual specific electricity consumption per m^2 is slightly higher for test group participants who went for “limited” (148 kWh/m and year) than for participants who were choosing the “excellent” option (121 kWh/m and year). This outcome might be an indicator for a lack of knowledge of how to save energy among customers with relatively high consumption.

Customer positions and attitudes regarding own consumption and energy saving was also investigated. The respondents were asked to consider six statements on a one to five scale (totally disagree – totally agree). Figure 7 depicts the sum of customer replies for “agree” and “totally agree”.

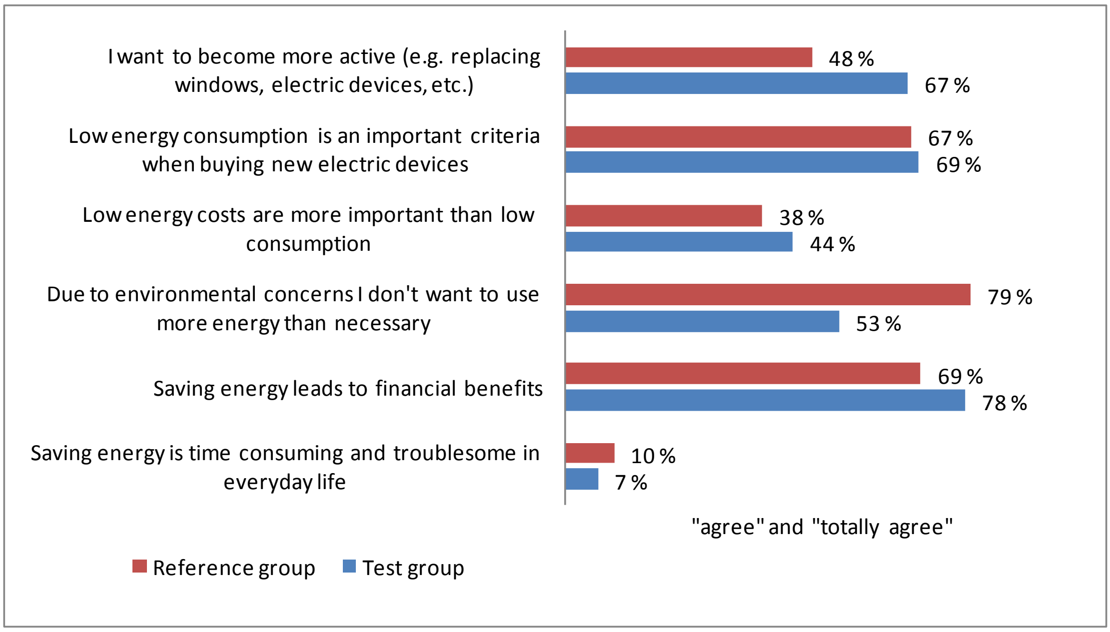


Figure 7 Customer positions and attitudes regarding own consumption

Low energy consumption of new electric devices is an important criterion for about 70 % in both groups. There are very few in both groups who experience energy saving as time consuming and troublesome in everyday life.

The rating of environmental concerns and plans on becoming more active clearly differs, with 79% for the reference group and 53% for the test group. Furthermore, it seems like more people in the reference group already are up-to-date and more conscious regarding their own consumption. There are considerably more people in the test group who want to change conditions at home and start becoming more active regarding their electricity consumption.

Further on, the participants were asked to consider four different actions concerning their habits related to the use of electricity in the home. Figure 8 summarises the test group replies and Figure 9 summarises the reference group replies (sum of “always” and “usually”).

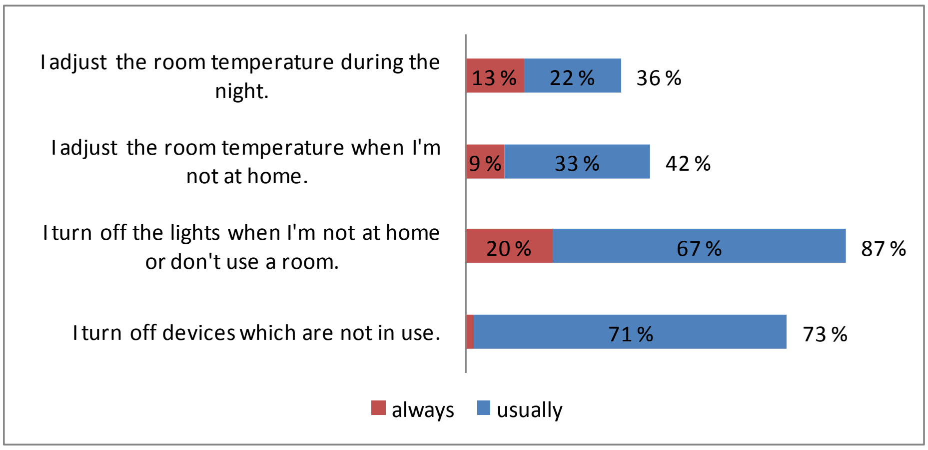


Figure 8 Customer habits – Test group

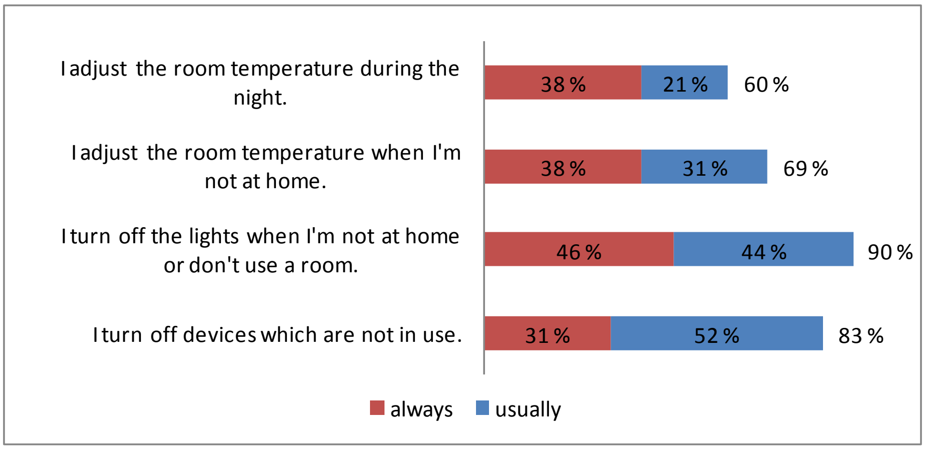


Figure 9 Customer habits – Reference group

There are clear differences between the test group and reference group customers. The reference group customers seem to have regular habits when considering the four different actions given in the survey question. The share of people who ticked the "always" option (turn off the lights and devices) is more than twice as large in the reference group (> 30 %). When it comes to adjusting the room temperature, the difference is even more distinct: the share of people who always adjust the room temperature ranges at 40 % in the reference group while it ranges only around 10 % in the test group. The share of people who usually adjust the temperature is about the same in both groups.

Since most of the test group participants use electrical devices for space heating, it is expected that this outcome implies a high saving potential. Customer habits will be followed up both in the next survey and by analysing the metering data available after the installation of the in-home display.

In-home display - Expectations

The customers in the test group were asked to assess motives for participating in the in-home display pilot. Their response on this survey question is shown in Figure 10.

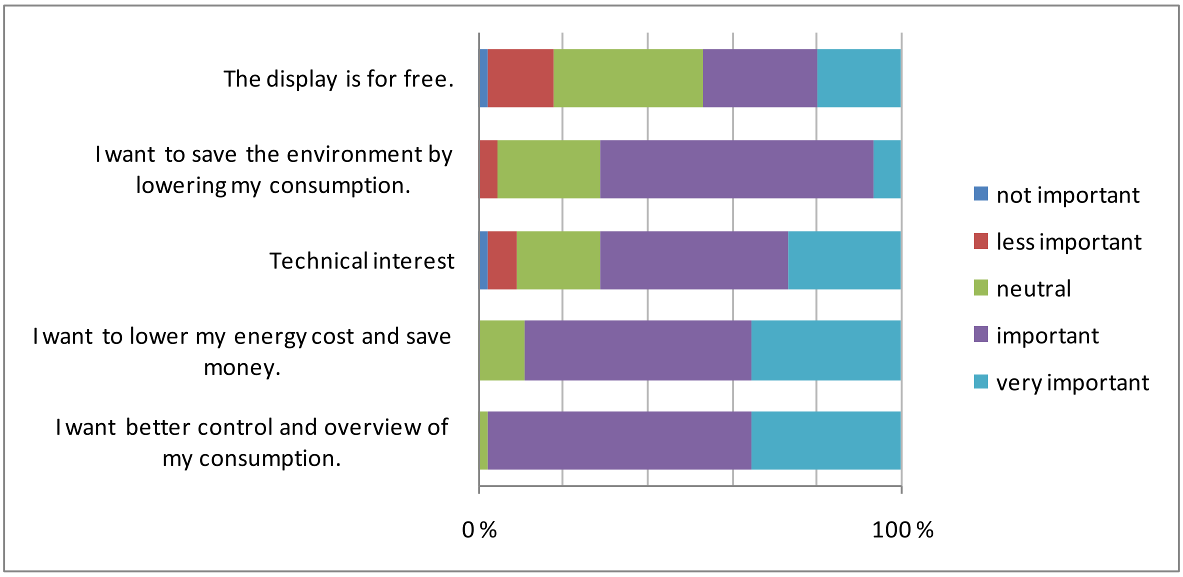


Figure 10 Reasons for participating in the pilot project

Most customers consider the possibility of getting better control and overview of their own consumption as crucial for their participation. In addition, it is quite important to save money for almost all of the customers. About two thirds of the customers show technical interest. The same share wants to lower their consumption due to environmental concerns. In this pilot study the customers get the display for free, but this fact seems to be less important for volunteering.

When asked how often they are expecting to use the in-home display during the test period, most customers chose the “several times a week” option (36 %). About 33 % expect a day-to-day use and about 27 % are expecting to use the in-home display several times a day. Only 4 % are expecting to use the display more infrequently – about once a week.

The last issue in the test group questionnaire focused on how they wanted their consumption data to be presented on the in-home display. Each customer could select several alternatives. Almost all customers (about 90 %) are especially interested in real-time consumption data (Figure 11).

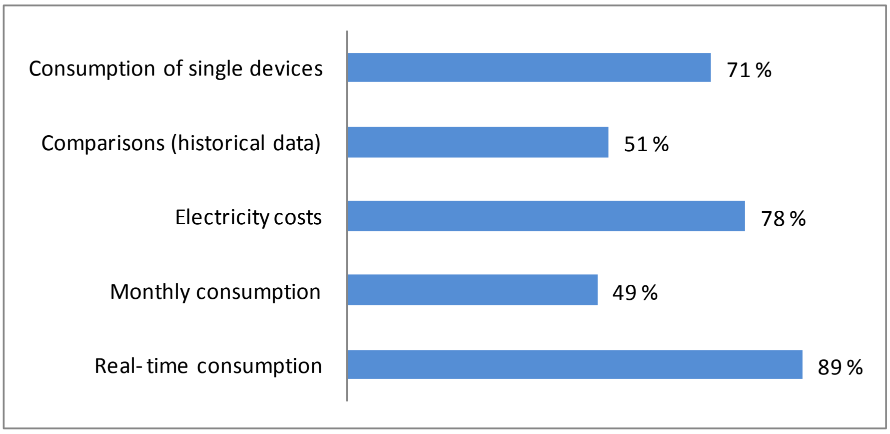


Figure 11 Presentation of consumption data preferred by customers

The presentation of real-time consumption data is followed by an electricity cost overview (78 %) and the presentation of the consumption of single devices (71 %). About half of the customers show interest for comparisons and/or their monthly consumption.

The option of showing real-time consumption data and the consumption of single devices is a big advantage of an in-home display compared to a web based presentation. The major part of the participants is interested in these viewing options of the in-home display.

The presentation mode preferred by the customers will be followed up in the next customer survey. The display has a built-in log for recording the customer’s activity (e.g. the push of a button) which is available in the pilot. Hence, one research task in the project will be to monitor if the customers are acting as expected by themselves in advance during the project period. Moreover, the pilot administration may send messages to the customers and test motivation strategies (e.g. comparisons).

Discussions

The test group customers volunteered for testing the in-home display. For this reason, they might be more than average motivated in saving energy and lowering their electricity consumption. The high response rate of the first test group survey might be an indicator of this. However, in comparison with the reference group customers, it seems that the reference group is more aware of their energy consumption than the test group. This difference is rather clear in the response of the survey questions on habits, attitudes and knowledge of how to save energy.

The main reason for the test group customers for participating in the project is getting better control of their electricity consumption. Nearly everyone in the test group considers the presentation of real-time consumption data and the consumption of single devices on the in-home display as very interesting. This might indicate that the majority of people in the test group now have little knowledge of how the total electricity consumption is composed by the consumption of single devices. Few have confirmed habits like turning off the lights or adjusting the room temperature which shows that most households have a high saving potential. The in-home display might be seen as a support tool for getting started with saving energy.

Another difference between the test and the reference group is the relevance of environmental aspects for saving energy. The reference group customers show a higher level of environmental awareness than the test group customers. The test group seems to prioritize the financial benefits related to energy savings. The importance of environmental aspects will be followed up in the project.

Further work

The next step in the research project will be the installation of the in-home display in the test group households. A major task after the installation will be the analysis of the metering data. The objective of this analysis is to quantify the amount of energy saved by the customers. It will be explored if and how the customers change their consumption pattern. The highest saving potential is expected with electrical space heating.

The next customer survey is scheduled three months after the display installation. Questions from the first survey will be repeated and followed up to monitor potential changes in customer habits. The customers will be asked to evaluate their experiences and the in-home display functionality more detailed. The pilot will be concluded with a third survey after the one-year testing period. The last survey includes both the test and the reference group customers. By means of customer response, it will be tried to distinguish between the impact of the in-home display and other factors affecting the energy consumption.

The other pilots planned in the project will be started up gradually. A broader sample of test and reference customers and metering data will allow for a more generalised view on and how an in-home display might influence the use of energy and the degree of energy efficiency in households.

References

[1] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: *A European Strategic Energy Technology Plan (SET-Plan). Towards a low carbon future*, 22/11/2007, COM(2007) 723 final

[2] European Smart Metering Industry Group. 29/04/2009, http://tdworld.com/smart_grid_automation/european-parliament-smart-metering-supporot-0409/

[3] Grinden, B. and Feilberg, N. *Analysis of Monitoring Campaign in Norway* EIE/05/124/SI2.419657, REMODECE-project, http://remodece.isr.uc.pt/

[4] Norwegian Ministry of Petroleum and Energy, Press Release, 12/01/2011 (in Norwegian) http://www.regjeringen.no/en/dep/oed/pressesenter/pressemeldinger/2011/tar-krafttak-for-automatisk-strommaling-.html?id=630569

[5] Darby, S. *The effectiveness of feedback on energy consumption. A review of Defra of the literature on metering, billing and direct displays.* Environmental Change Institute, University of Oxford, April 2006.

[6] Fischer, C. *Feedback on household energy consumption: a tool for saving energy?* Energy Efficiency (2008): 1:79-104, DOI 10.1007/s12053-008-9009-7

[7] German feedback project *Intelliekon*, www.intelliekon.de

[8] A report for the Energy Saving Trust by the Centre for Sustainable Energy. *The smart way to display. A summary report on consumer preferences for energy display designs*, 2009. http://www.cse.org.uk/downloads/file/(CO183) The Smart Way to Display.pdf

Do Smart Metering Services Lead To Energy Savings? A Dynamic Landscape With Little Empirical Evidence

Stephan Renner

Austrian Energy Agency (AEA)

Abstract

While one feature is similar to all EU Member States and that is the Third Energy Market Package (Directives 2009/72EC and 2009/73/EC) that serves as a strong driver towards intelligent metering systems, there are also important differences between the Member States. The Smart Metering Landscape Report gives a detailed overview of the dynamics in the modernisation of Europe‘s metering infrastructure and lists a range of services that become possible with data from smart meters. At the same time, however, there is only limited empirical evidence to what extend advanced metering services will actually lead to energy savings. This paper provides an overview and argues that future legislation (such as a review of the Energy Services Directive) should focus on the required service to the final customer.

Introduction

Intelligent metering systems (smart meters) can have several benefits. One of these is that data collected by smart meters can be used to give the final customers additional feedback about their energy consumption which can, in turn, lead to greater awareness about their energy use and potentially to energy savings [14]. However, the introduction of advanced metering contains costs too. These costs not only include investment costs and maintenance costs of the metering system, but also non-monetary costs, such as, for example, interventions into the privacy of households. The intensity of these interventions depend on the frequency of data collection and transmission.

At the Steering Committee of the EU Smart Grid Taskforce it was stressed that all necessary measures need to be undertaken in order to ensure maximizing the usage of smart grids benefits by the end users/consumers on one hand and protection of end users/consumers' interests on the other. This is important because it will be difficult to convince customers about the added value of new metering technology and the modernisation of the European electricity grids, if metering data is only beneficial for utilities (to reduce non-technical losses, for remote reading and switching or the simplification of billing procedures, etc.). Metering services will provide added value to the consumers only if they are tailor-made, respect the right for privacy and respond to the individual need for additional information about energy consumption.

This paper givens an overview of the legal and regulatory progress in the introduction of smart metering in EU27 Member States and Norway. Moreover, it provides examples of feedback and information tools that are trialled or already used on a commercial basis. Finally, this paper discusses if information and feedback has the potential to achieve energy savings at all. The information for this paper was collected within the project "Smart Regions." The goal of this project, financed by the Intelligent Energy Europe programme (IEE), is to promote innovative smart metering services that have the potential to achieve energy savings and peak load reduction in all Member States. In order to do this, the first deliverable of this project is the European Smart Metering Landscape Report[1] that provides information on the state of the metering infrastructure as well as the services that are being developed, tested or already offered in the market.

---

[1] The European Smart Metering Landscape Report is a Deliverable of the project "SmartRegions – Promoting best practices of innovative smart metering services to European regions" funded by Intelligent Energy – Europe (Contract N°: IEE/09/775/S12.558252) with contributions from Mihaela Albu, Henk van Elburg, Christoph Heinemann, Artur Łazicki, Lauri Penttinen, Francisco Puente, Hanne Sæle and Stephan Renner (co-ordinating autor). The full report and more information can be found at www.smartregions.net.

Regulatory push

The legislative push by the European Union's Third Energy Market Package is currently the main driver for the introduction of intelligent metering systems in Europe [24]. For the introduction of smart metering in EU member states, there are two directives that act as drivers: the so-called Energy Services Directives (2006/32/EC, ESD) and the so-called Third Energy Package and particularly Directive 2009/72/EC. Additionally, the recast of the Energy Performance of Buildings directive (2010/31/EU, EPBD) includes a provision on the introduction of intelligent metering systems.

The landscape of advanced metering deployment only represents a snapshot that will – due to the dynamic nature of the current situation – have to change soon. With the transposition of the Third EU Energy Market Package all EU Member States will in some form have to discuss its requirements. Annex I(1)(i) states that consumers must be properly informed of actual electricity consumption and costs frequently enough to enable them to regulate their own electricity consumption. This provision is similar to Art. 13 of the Energy Services Directive [25].

Moreover, as part of measures on consumer protection as listed in Annex I, Member States shall ensure the implementation of intelligent metering systems. The implementation of those metering systems "may be subject to an economic assessment of all the long-term costs and benefits to the market and the individual consumer or which form of intelligent metering is economically reasonable and cost-effective and which timeframe is feasible for their distribution." Where rollout of smart meters is assessed positively, the Directive demands that at least 80 % of consumers shall be equipped with intelligent metering systems by 2020.

Since the installation of electronic meters is not a means by itself but the overall goal is to reduce energy consumption and shift peak load demand, the key to a successful implementation will be the related services that are possible with data from smart meters. Metering technology is, after all, just an enabler for further improvements in the distribution networks. The modernisation of the electricity grids is key for the integration of highly volatile sources of electricity such as wind. An intelligent grid does not stop at electricity production but includes flexible consumers that help to balance demand and supply.

Implementation of Smart Metering in Europe

Due to the regulatory push by the EU, the smart metering landscape currently is highly dynamic with many Member States adjusting their energy law to comply with the energy market package and the Energy Services Directive (ESD). Based on the information gathered in this Smart Metering Landscape Report all EU Member States plus Norway were analysed along two dimensions:

1. **Legal and regulatory status:** By the legal and regulatory status we evaluate whether or not a framework has been created to not only provide clear guidelines to utilities for the installation of meters but to do so with the goal of achieving energy savings and/or peak load shifting.

2. **Progress in implementation:** By the progress in implementation we not only refer to the number of pilot projects, smart meters and corresponding services in the field, but also the existence of and progress towards a clear and realistic implementation roadmap for metering technologies that enable metering services with, again, the goal of achieving energy savings and/or peak load shifting.

Along these two dimensions we distinguished between five groups: Dynamic movers, market drivers, ambiguous movers, waverers and laggards. Figure 1 provides a graphical account of the smart metering landscape in Europe.

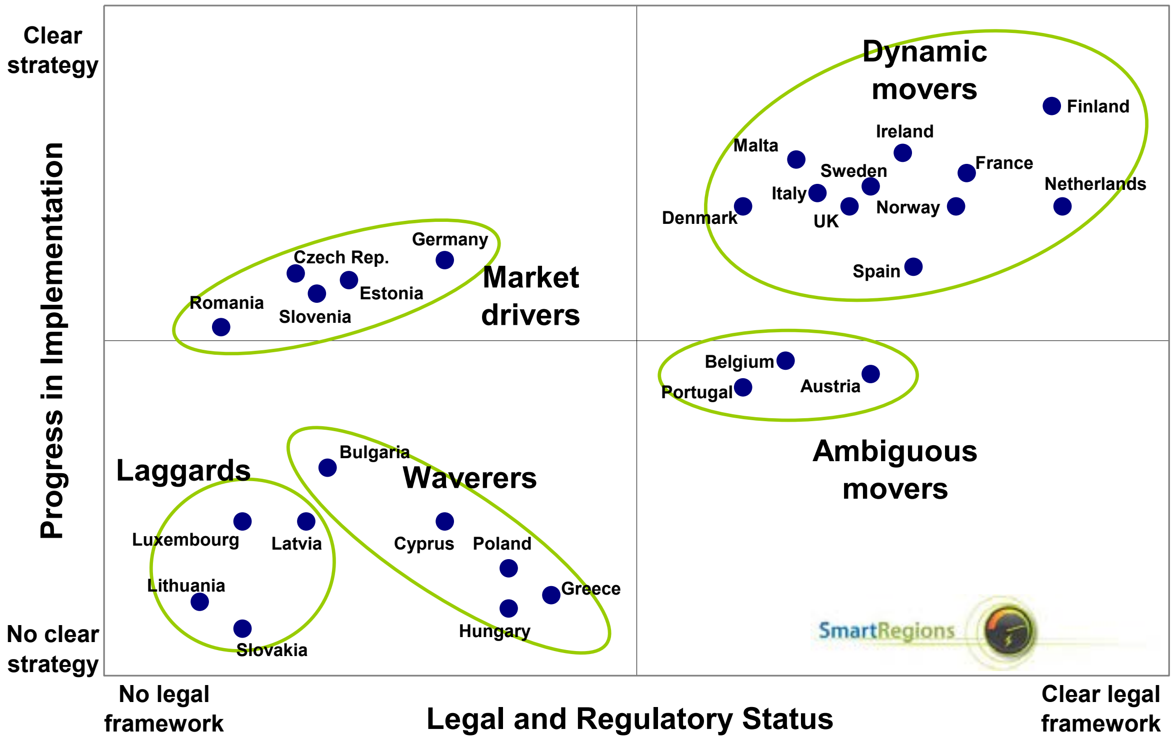


Figure 1: Smart metering lanscape in Europe [24]

Dynamic movers

The "*dynamic movers*" are characterised by a clear path towards a full rollout of smart metering. Either the mandatory rollout is already decided or there are major pilot projects that pave the ground for a subsequent decision. Denmark, Finland, France, Ireland, Italy, Malta, The Netherlands, Norway, Spain, Sweden and UK are part of this group.

Sweden, for example, was the first country to (indirectly) mandate a full rollout of smart meters. Since July 2009 monthly meter reading is required for smaller customers. A cost-benefit-analysis resulted in net benefits of more frequent meter readings. However, there are no mandatory requirements for remote meter reading of gas, heat and water and no legal basis for hourly metering in households, which is, however, the basis for many services.

Finland, France, Spain, Italy and Malta chose similar strategies, namely to create a legal obligation for the actors responsible for the metering of electricity to either install adequate electronic meters or to provide a certain level of service to the final customers. In Finland, with 1 million electricity meters already installed, the Electricity Market Act demands a smart meter penetration rate of 80% by 2014. France envisages a smart metering coverage of 95% in electricity by 2016 and prepares legislation for a mandatory rollout. Spain adopted a binding meter substitution plan for the period until the end of 2018 that is now in the process of being implemented by the DSOs despite some difficulties at the start. In Italy, the DSOs have completed the substitution of the metering infrastructure to reduce non-technical losses in the network.

Norway and Denmark have both early endorsed a full rollout but later reviewed their decision and postponed the start of a meter replacement program. In Norway, a proposal for a full rollout and functional requirements was postponed in late 2009 in order to wait for European standards. In January 2011, the Ministry of Petroleum and Energy asked the Norwegian regulator to submit a proposal for earlier installation of smart metering technology in Central Norway by 2013 and a full rollout by 2016. A discussion document is published in February 2011. In Denmark, the mandatory metering of the electricity consumption of household customers has been suggested, but a cost-benefit-analysis led to a negative result. Nevertheless, in all countries of the group of "ambiguous movers" some dynamics is expected in 2011.

The Netherlands serves as an example of how the lack of broader public debate may postpone or even stop the installation of smart meters altogether. Privacy concerns first led to the abolition of a mandatory rollout plan. After a fierce public debate, Dutch Parliament in November 2010 finally adopted a legal framework for voluntary installation of smart metering. Customers may choose between four alternatives (from keeping conventional meters to full Automatic Meter Readings, AMM). Since privacy concerns dominated public discussions, smart meters need the option for an "administrative off" and a port for decentralised metering services (real-time feedback with data remaining in the house, etc.).

While Malta started with an ambitious rollout in 2010 to replace all electricity and water meters of 245,000 consumers by the end of 2012, it is also an example of how the replacement of meters becomes a delicate political issue. There have been some serious troubles with electricity bills that were issued by Automated Revenue Management Services, Ltd (ARMS). Instead of receiving electricity bills of their actual consumption, many customers still receive estimated bills or no bills at all. In November 2010, the government of Malta has even approved an investigation into the running of the rollout and the alleged mismanaged handling of water and electricity bills.

Other dynamic movers clearly support the plan of a rollout yet base a final decision on ongoing trials. Two favourable examples can be found in Ireland and the UK. In Ireland, the national regulator (CER) initiated a major pilot project with network operators to acquire technical experience and test around 6,000 customers (households, SMEs) on how they react to additional feedback. In four groups different forms of feedback to the final customer are tested (monthly billing, bi-monthly billing, in-house displays, overall load reduction). The results of all these trials will feed into a cost-benefit analysis by early 2011, which in turn will inform decisions related to any national rollout of smart meters.

In the UK, government already made a decision in principle for a full rollout. However, a consultation process was started to define the exact terms. Contrary to most other EU Member states, the main energy suppliers, rather than distribution networks, will be responsible for the rollout of the meters. The relevant ministry (DECC) in July 2010 published a smart metering prospectus outlining the rollout strategy which has been fed by first results of the Energy Demand Research Project (EDRP), a major research project where four suppliers trial the effect of additional feedback to the final customers. A final report of the EDRP is expected in 2011.

Market drivers

The second group ("market drivers") consists of countries where there are no legal requirements for a rollout. Some DSOs or legally responsible metering companies nevertheless go ahead with the installation of electronic meters either because of internal synergetic effects or because of customer demands. We classified Estonia, Germany, Czech Republic, Slovenia, and Romania in this group.

A typical example for this group of market drivers is Germany. In Germany, a mandatory rollout is not yet planned. The country rather follows a policy driven by customer demand. A range of pilot projects are currently ongoing.[2] The metering service is liberalised. The national legislation (EnWG 2009) only demands the installation of smart meters in new buildings and buildings that are undergoing major refurbishing from the beginning of 2010. Moreover, by 2011 electricity suppliers have to offer load-variable or time of use tariffs. Minimum functional requirements are not available and also a cost-benefit-analysis has not been carried out yet. However, with the implementation of the Third Package a regulatory push is expected.

Similarly, there is no legal obligation for a rollout in Slovenia, Czech Republic or Estonia. Nevertheless, in Slovenia one regional DSO (Elektro Gorenjska) has decided to start a full scale role out for all of its about 80,000 customers in 2011. In the Czech Republic ČEZ announced a multi-energy pilot including 40,000 meters, feedback to customers and data acquisition and has plans to roll

[2] See, for example, the project regions in the E-Energy program: www.e-energy.de/en/

out 1 million meters by 2015. In Estonia, the dominant DSO OÜ Jaotusvõrk is planning a major roll-out (680 000 meters) to be implemented in 2011 - 2017.

Ambiguous movers

The third group only consists of Austria, Belgium and Portugal and represents a situation where a legal and/or regulatory framework has been established to some extent and the issue is high on the agenda of the relevant stakeholders ("ambiguous movers"). These countries have dealt with cost-benefit-analysis and/or functional requirements. However, due to lack of clarity within the framework, only some DSOs have decided to install smart meters yet and some have cautiously postponed a decision on a mandatory rollout.

In Austria, in late 2010 the legislator has finally decided to establish some form of legal framework for smart metering. According to the new Electricity Act (ElWOG 2010), the Minister of Economy may introduce smart metering per decree, following a cost-benefit-analysis. The regulator may define functionalities and data requirements of a smart metering system. However, due to the lack of clarity of the new electricity law, it will probably not be an immediate push for a rollout of smart metering. The law does not determine the design of a smart metering system but merely assigns decision-making powers from the legislator to the responsible ministry and the regulator and leaves the responsible DSOs again with little clarity. A similar unsettled picture can be found in Belgium.

In Portugal there is no legal framework for a mandatory rollout yet. However, in 2007, the regulator presented a meter substitution plan for the period 2010-2015 and a list of functional requirements that is co-ordinated with neighbouring Spain. Moreover, in 2010 a consortium led by EDP Distribuição started the project InovGrid where around 50,000 smart meters will be installed in several points of the country. EDP also presented the project InovCity for the city of Évora with 30,000 meters. All in all, however, the ambiguous movers still lack the clarity that would drive a full rollout.

Waverers and Laggards

The countries in the forth group are termed "waverers" which means that there is some interest in smart metering from the regulator, the utilities or the ministries. However, corresponding initiatives have either just started, are still in progress or have not resulted in a regulatory push towards smart metering implementation. We rank Bulgaria, Cyprus, Greece, Hungary and Poland in this group.

Poland started with an ambitious national energy platform and founded a smart grid consortium to support the implementation. In Cyprus an amendment of the energy law is expected by the end of March 2011 and a cost-benefit-analysis is expected by July 2012. In Hungary, a cost-benefit-analysis was carried out in 2010 with the recommendation to implement a system with legally separate but regulated meter operators and to start the rollout for domestic customers in 2014. Greece has also decided on a rollout and has defined minimum functional requirements, however without setting a concrete date. In Estonia, a large-scale rollout is under discussion. Finally, in Bulgaria, while there is no legal obligation, a considerable number of electronic meters with remote reading have been installed since 2006 in order to reduce non-technical losses and the number of complains about erroneous invoices.

Finally, the fifth group consists of *laggards*. We classify countries as laggards if smart metering is not an issue yet. This group consists of Latvia, Lithuania, Luxembourg and the Slovak Republic. However, since transposition of Directive 2009/72EC is ongoing it is not unlikely that the laggards suddenly gain momentum.

Examples for information and feedback to customers based on metering data

The introduction of intelligent metering system in Europe is not customer- but regulatory-driven. That is, meters are – to a large extent – not introduced on customer demand but because it is a legal obligation or economically beneficial for utilities. Unlike in the telecommunications sector, where it is the customer who demands new devices and applications, in the energy sector it is the legislature that demands the substitution of the conventional meters. Hereby, the legislator pursues two goals: energy efficiency and consumer protection.

However, meters and metering technology do not save energy by themselves[3] but are just enabler for metering services. It is conscious use of additional services by the consumer that my lead to changes in the energy consumption. Information and both direct and indirect forms of feedback to consumers such as frequent billing options, internet-portals, in-house displays or mobile solutions are now employed by all major energy utilities that use smart meters. Some of these services are explicitly tested.

The Energy Demand Research Project (EDRP) in the UK, for example, tests informative and frequent billing in 13,000 households and smart meters combined with feedback on in-house displays, TV or internet in 17,000 households. Additionally, the option of sensors that send data to visual display units clipped on to conventional meters is tested in 8,000 homes.[4] In the UK the effects of engaging customers in local communities is also being trialled by one supplier. A community receives a financial reward of £20,000 if it manages a 10% reduction in consumption.

The final results of these trials is expected in the course of 2011. Some initial results indicate that smart meters can indeed be a vehicle for effective action to reduce domestic energy demand. However, "improved feedback emerges as necessary for good understanding of energy use, but not always sufficient for effective action" [19]. The focus on technology alone is unlikely to have a major effect on consumption. One important lesson is that technology and information need to be tailored to individuals and households rather than adopting a 'one-size fits all' approach [19].

Ireland is another good example of how feedback mechanisms can be systematically tested and the results fed into the political process. In four test groups and a total of 5,500 household different forms of feedback to the final customer are tested (monthly billing, bi-monthly billing, in-house displays, overall load reduction). The results of all these trials will feed into a cost-benefit analysis by early 2011, which in turn will inform decisions related to any national rollout of smart meters [16] [32].

There is a steady improvement and refinement of displays with the development of a basic entry level display and, at the same time, the development of higher specification models providing greater levels of functionality. The display-market received a particular push by regulatory decisions to create an obligation to supply displays to customers, such as in the UK [9]. Because of this obligation, energy providers such as Scottish Power have issued in-house displays to a majority of its customers. It is too early to report results of this form of direct feedback, however initial results suggest that it is important to prevent customer's interest to fade away after some early enthusiasm (see also, for example [1][4][10][13][27][31]).

In the Netherlands and in the UK as part of the Energy Demand Research Projects utilities offered financial rewards if consumers achieve savings. In the Netherlands Oxxio rewards the clients who are able to save 10 % less in three years with a cash payment of EUR 300. Whether or not this has an actual effect on energy consumption has yet to be proved. In the UK as part of the EDRP one trial combines energy-saving tips with a financial incentive to reduce energy consumption. Households were offered a £10 voucher if they managed to keep their energy consumption below a target defined by their historical consumption. Ofgem reports immediate and dramatic results with a pronounced fall in the electricity consumption of the group receiving the intervention [20]. However, this effect only lasted as long as the reward served as a goal. Once the households had received their reward, their energy savings began to decline and were entirely gone around seven months later. Ehrhardt-Martinez et al. affirm these findings [8].

---

[3] On the contrary, an intelligent metering system will consume more electricity than conventional meters. In a cost-benefit analysis for the advocacy group for the Austrian electricity industry it is assumed that intelligent grid infrastructure (meters, concentrators, communication, etc.) increases power consumption in 2020 compared to the current system by 67% in case of a 80% rollout [33]. In the UK, DECC assumes around 18 kWh of electricity consumption for meter, display and the communication equipment at the consumer site [7].

[4] A similar service is offered by the Electronic Housekeeper (www.electronichousekeeper.com) or the "Wattcher" in the Netherlands, a design display that shows a consumers home's total electricity consumption. The Wattcher consists of a sensor, a sending unit and a display. The sensor can be placed on any electricity meter. The sending unit sends a radio signal to the display unit, which can be placed in any (euro standard) electricity socket. The Wattcher can be self installed by the consumer. An independent evaluation of achieved energy savings is not available. However, the Wattcher was nominated for the Dutch Design Award 2009 and has won the ICT Environment Award 2010.

Major internet players such as Google also entered the metering service market. Google offers its PowerMeter for private customers in cooperation with energy utilities (such as First Utility (UK), JEA, San Diego Gas & Electric (USA) and Yellow Strom in Germany). The PowerMeter can be installed as a widget on the customers' iGoogle homepage. It shows the energy consumption in 15 minutes intervals. This is done by using block or line charts. It is also possible to show historical consumption data. In addition a social comparison on the basis of the German standard load profile is carried out and shown. An independent assessment of the service has not been carried out yet. Compared to other feedback systems the design, the usability and issues of privacy and data protection are on a low level. Nevertheless, the widget has got one main advantage compared to other feedback systems: Because it is situated on the iGoogle site most users will look at the widget every time they use the internet.

Based on the data from smart meters different companies develop internet portal as well as a mobile application for Apple's iPhone, iPod touch or iPad. The mobile application GreenPocket Mobile shows the consumption, the costs and the CO_2 emission on a daily, weekly, monthly and yearly basis. The important data is displayed in a clear and easy to use way. For these mobile applications it is clearly the style factor that might help to keep the interest on feedback.

What evidence for energy savings?

While these reports suggest that metering services that provide information and feedback to the consumer have some influence on energy consumption behaviour, to what extent information and feedback in fact achieve energy savings is still contested by the literature (for an overview see, for example, [3-6][8-9][11][13][15-16][20-21][27-28][30].

Darby, for example, argued in an earlier and since then frequently cited piece that savings from direct feedback (immediate, from the meter or an associated display monitor) may range from 5-15% and savings from indirect feedback (feedback that has been processed in some way before reaching the energy user, normally via billing) have ranged from 0-10% [5]. However, the projects listed in her study are diverse and range from self-reading of the meter to electronically processed data from a clip-on on a conventional meter.

Ehrhardt-Martinez et al. recently published a review of different feedback studies [8]. They argue that the saving effect largely depend on the form of feedback and may range between 4-12 %. Daily or weekly feedback and real-time plus feedback tend to generate the highest savings per household. However, the results of the studies depend on the design of the studies, e.g. the number of test-persons that take part. The savings effects tend to be lower in larger and longer studies than in smaller and shorter studies. Additionally, the savings depend on the social composition of a target group. Younger Households with higher education and income as well as a general positive environmental attitude tend to achieve the highest saving effects.

Even EU Commissioner for Energy, Günther Oettinger, highlighted the importance of feedback in an answer to a parliamentary question and referred to recent research by Joint Research Centre in Ispra that indicates that instantaneous direct feedback in combination with frequent, accurate billing is needed as a basis for sustained demand reduction. It is argued that direct displays in combination with improved billing seem to result in early energy savings at a relatively low cost [15].[5] Moreover, the European Commission assumes in its recent Smart Grids Communication that consumers with smart meters installed reduce their annual energy consumption of around 10% and more [34].

However, the results from the above mentioned feedback studies were mostly achieved not with smart meters, but with manual meter reading which were then interpreted and sent to the households [6]. Additionally, the involvement of the participating households usually involves selection bias to some extent. In a nationwide rollout, these participation rates may not be achieved. There is no empirical long-term information available as to which types of customers can be influenced in their consumption behaviour by which kind of feedback.

---

[5] Answer to a parliamentary question given by Mr Oettinger on behalf of the European Commission on 1 September 2010 (E-6199/2010). http://www.europarl.europa.eu/sides/getAllAnswers.do?reference=E-2010-6199&language=ET

In the absence of reliable empirical data and in order to evaluate the added-value of a smart metering rollout, some EU Member States carried out their cost-benefit analysis basically based on assumptions regarding the expected energy savings. In the UK (Table 1), with reference to the literature [5][8][11], DECC and Ofgem assume savings in the range of 1.5–4.0% for electricity and 1.0 – 3.0% savings for gas (0.3 – 1% for gas pre-payment meters) [7].

Table 1: Assumed savings from feedback for UK Impact Assessment to DECC [7]

	High benefits	Medium benefits	Low benefits
Electricity	4,0 %	2,8 %	1,5 %
Gas	3,0 %	2,0 %	1,0 %
Gas Pre-Payment	1,0 %	0,5 %	0,3 %

In a cost-benefit analysis for the Netherlands, SenterNovem and KEMA assumed savings of 2% for both electricity and gas [26]. In an update to the cost-benefit analysis in July 2010, reflecting the changed legislative framework in the Netherlands, Gerwen et al. differentiated between direct and indirect feedback and assumed savings for electricity between 0 and 11.5%, depending on the motivation of the customer to get involved (Table 2) [12].

Table 2: Energy savings potential of direct and indirect feedback for the Netherlands [12]

Savings	Feedback	Savers			National average
		unsusceptible	already convinced	persuasible	
Electricity	Indirect	0.0%	2.0%	6.0%	3.2%
	Direct	0.0%	5.0%	11.5%	6.4%
Natural gas	Indirect	0.0%	3.0%	6.5%	3.7%
	Direct	0.0%	4.0%	9.0%	5.1%

In a cost-benefit analysis in Hungary the authors assumed savings in the range of 1% for electricity and 1.5% in the gas sector [2]. In Austria, a cost-benefit analysis for the regulator assumed electricity savings of 3.5% for electricity and 7% for gas with feedback from an online platform and a monthly energy and price information [22]. However, these assumptions are strongly contested by a wide range of stakeholders. Belgium assumes energy savings in electricity of 1.5-2.5% and in gas of 1.5-3%. However, the maximum energy saving is only expected with direct feedback through in-house displays.

In sum, there is some evidence for the potential of energy savings. However, this evidence is incoherent, depend on the design and size of the pilot study and is largely difficult to compare. Many of the studies that achieved large energy savings were not conducted with smart meters and suffer from a so-called optimism bias [7]. The larger studies in the UK and Ireland so far indicate that the energy savings will be much lower than the enthusiastic estimates by the European Commission and others.

There is no doubt that information about one's actual energy consumption is an important requirement to use energy consciously and eventually even less of it. However, in order to actually reach these savings, there are (at least) two necessary conditions:

- First, energy customers need to participate, show some interest and have to get involved. Without their participation and their conscious behaviour it is – at least for feedback mechanisms – virtually impossible to have a causal impact on their energy consumption. Since the introduction of smart metering in Europe is driven by regulation and legislation, the customer's involvement cannot be taken for granted yet.

- Secondly, with due respect to the right for privacy of consumers and also the right to be not interested in energy consumption (on the issue of privacy see, e.g. [18][23][29]), smart metering can only have an effect on energy consumption when appropriate services are offered that use the metering data. There is a range of other sufficient conditions to achieve energy savings yet the metering infrastructure needs to be in place.

Conclusions

The smart metering landscape in Europe is dynamically moving. The main driver is the legislative push by Directive 2009/72/EC. Almost all Member states have started a debate on a strategy to introduce smart metering. Dynamic movers (Denmark, Finland, France, Ireland, Italy, Malta, Netherlands, Norway, Spain, Sweden and UK) lead the development and have either decided on a mandatory rollout already or started major pilot projects that pave the ground for a subsequent decision.

However, as the example of Italy shows, upgrading the metering infrastructure alone does not provide added-value to the consumer and will not have effects on energy savings. In other words, metering consumption alone does not save energy! What is required are innovative services based on metering data. Such services must be designed in a way to meet the consumers interest to know more about their energy consumption. If metering infrastructure is beneficial only for utilities and without involving the final customer, savings will not only be very unlikely but virtually and causally impossible.

However, not all consumers are equal and some consumers, as is mentioned in the recent Dutch cost-benefit analysis [12], are unsusceptible for additional information and feedback. Moreover, some consumers have serious concerns about unnecessary interventions into the privacy of their homes. As a consequence, at the 7th Steering Committee meeting of the EU Smart Grid Taskforce on 27 October 2010 it was stressed that all necessary measures need to be undertaken in order to ensure maximizing the usage of smart grids benefits by the end users/consumers on one hand and protection of end users/consumers' interests on the other. Moreover, Expert Group 2 of the Taskforce was asked to reach an agreement whether the smart grids deployment might require specific additional European regulation on consumers' data protection, handling, and security on which Member Sates and national regulatory authorities can base their own decisions.[6] Consequently, smart metering should serve the needs of energy end-users and respect their right for privacy.

Any additional smart grid regulation has to balance between possible functionalities and services to achieve energy savings and peak load reduction and concerns about the security of a smart grid, possible privacy intrusions, etc. As argued by the European Regulators (ERGEG), is always the customer that chooses in which way metering data shall be used and by whom. In order to guarantee that end-uses will benefit from advanced metering, any future regulation (such as a review of the Energy Services Directive) needs to focus on the required service to the final customer and not to the details regarding the metering requirements. It is the services that an intelligent metering system can deliver that matter to the end-user, not the meters by themselves. Advanced metering can only have an effect on energy consumption when appropriate services are offered to end-users that provide clear, precise and up to date information on energy consumption.

---

[6] European Commission, Directorate-General for Energy and Transport. Meeting minutes from the 6th meeting of the Steering Committee of the Task Force for Smart Grids, 03.11.2010, Brussels.

References

[1] Anderson, W./V. White, 2009. Exploring consumer preferences for home energy display functionality. Centre for Sustainable Energy.

[2] AT Kearney/Force Motrice, 2010. Assessment of Smart Metering Models: The Case of Hungary. 18 June 2010.

[3] Benders, R.M.J./R. Kok/H.C. Moll/G. Wiersma/K.J. Noorman, 2006. New approaches for household energy conservation—In search of personal household energy budgets and energy reduction options. Energy Policy, 34(18), 3612-3622.

[4] Caiger-Smith, P./J. Burgess, 2010. Visible Energy Trial, Metering Europe 2010, 23 September 2010, Vienna.

[5] Darby, S., 2006. The Effectiveness of Feedback on Energy Consumption. A Review for DEFRA of the Literature on Metering, Billing and Direct Displays. Environmental Change Institute, University of Oxford, Oxford, April 2006.

[6] Darby, S., 2010. Smart metering: what potential for householder engagement? Building Research & Information, 38(5), 442-457.

[7] DECC, 2010. GB-wide smart meter roll out for the domestic sector. Department of Energy and Climate Change, London, 27.07.2010.

[8] Ehrhardt-Martinez, K./K.A. Donnelly/J.A. Laitner, 2010. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving. American Council for an Energy-Efficient Economy (ACEEE), Washington, June 2010.

[9] ESMA, 2010. Annual Report on the Progress in Smart Metering. European Smart Metering Alliance, January 2010.

[10] Firet, L./C. Ijsbrandy, 2010. Promising results: energy savings through direct feedback on household's gas and power consumption in The Netherlands. VaasaETT, Helsinki.

[11] Fischer, C., 2007. Influencing Electricity Consumption via Consumer Feedback: A Review of Experience. Proceedings of the ECEEE 2007 Summer Study on Energy Efficiency, 9, 1873-1884.

[12] Gerwen, R.v./F. Koenis/M. Schrijner/G. Widdershoven, 2010. Smart meters in the Netherlands. Revised financial analysis and policy advice KEMA Nederland B.V. by order of the Ministry of Economic Affairs Arnhem, NL, 13 July 2010.

[13] Hargreaves, T., 2010. The Visible Energy Trial: Insights from Qualitative Interviews. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, February 2011.

[14] Kester, J.C.P./M.J. González Burgos/J. Parsons, 2009. Smart Metering Guide - Energy Saving and the Customer (Edition 2010). European Smart Metering Alliance (ESMA), 16 November 2009.

[15] Langenheld, A., 2010. Advanced metering and consumer feedback to deliver energy savings – Potentials, Member States experience and recommendations. Report prepared by the Joint Research Centre of the European Commission (unpublished), Ispra, March 2010.

[16] Mannion, C., 2010. Smart Metering Trials in Ireland. Metering International, (3/2010), 60-62.

[17] Mountain, D., 2006. The Impact of Real-Time Feedback on Residential Electricity Consumption: the Hydro One Pilot. McMaster Institute for Energy Studies & DeGroote School of Business, McMaster University, Ontario, March 2006.

[18] NIST, 2010. Guidelines for Smart Grid Cyber Security: Vol. 2, Privacy and the Smart Grid. National Institute of Standards and Technology, U. S. Department of Commerce, Gaithersburg, August 2010.

[19] Ofgem, 2010a. Energy Demand Research Project - Progress report December 2010. Office of Gas and Electricity Markets (Ofgem), London, 20 December 2010.

[20] Ofgem, 2010b. Energy Demand Research Project - Review of progress for the period March 2009 - September 2009. Office of the Gas and Electricity Markets, London, March 2010.

[21] Owen, G./J. Ward, 2010. Smart Tariffs and Household Demand Response for Great Britain. Sustainability First, London.

[22] PwC, 2010. Studie zur Analyse der Kosten-Nutzen einer österreichweiten Einführung von Smart Metering. PwC Österreich im Auftrag der E-Control, Wien, Juni 2010.

[23] Reinders, B./B. van den Berg, 2010. Security & Privacy Framework Smart Metering, Metering Europe 2010, 22 September 2010, Vienna.

[24] Renner, S./M. Albu/H. van Elburg/C. Heinemann/A. Łazicki/L. Penttinen/F. Puente/H. Sæle, 2011. European Smart Metering Landscape Report. Deliverable 2.1 of the IEE-Project "SmartRegions". Austrian Energy Agency, Vienna, February 2011, www.smartregions.net.

[25] Renner, S./F. Martins, 2010. Individual metering and informative billing. Technical Summary Report TSR03. Concerted Action Energy Services Directive funded by Intelligent Energy Europe (IEE)

[26] SenterNovem, 2005. Recommendation - Implementing smart metering infrastructure at small-scale customers. Utrecht, Oktober 2005.

[27] Sipe, B./S. Castor, 2009. The Net Impact of Home Energy Feedback Devices. 2009 Energy Program Evaluation Conference, Portland.

[28] Stromback, J., 2010. A Comparison of 80 Demand Response and Feedback Pilots, Metering Europe 2010, 23 September 2010, Vienna.

[29] TF Smart Grids, 2010. Expert Group 2: Regulatory Recommendations for Data Safety, Data Handling and Data Protection. EU Commission Task Force for Smart Grids, Brussels, 29 July 2010.

[30] van Elburg, H., 2008. Report on Effective Customer Feedback Mechanisms. European Smart Metering Alliance (ESMA), Deliverable 6, Workpackage 2, Tasks 2 and 3.

[31] Warren, A., 2010. Smart meters are only part of the answer. Utility Week, (24 September 2010), 11.

[32] Wynne, J., 2010. Large-scale Smart Meter Customer Trial. A retailers perspective, Metering Europe 2010, 23 September 2010, Vienna.

[33] Capgemini (2010). Analyse der Kosten – Nutzen einer österreichweiten Smart Meter Einführung, Studie für den Verband der Elektrizitätsunternehmen Österreichs (VEÖ), Jänner 2010, Wien.

[34] European Commission (2011). Smart Grids: from innovation to deployment (Communication), European Commission, 12 April 2011, Brussels.

[35] ERGEG (2011). Guidelines of Good Practice on Regulatory Aspects of Smart Metering for Electricity and Gas, European Regulators' Group for Electricity and Gas (ERGEG), 8 February 2011, Brussels.

Using Wireless Power Meters to Measure Energy Use of Miscellaneous and Electronic Devices in Buildings

Richard Brown[1], Steven Lanzisera[1], Hoi Ying (Iris) Cheung[1], Judy Lai[1], Xiaofan Jiang[2], Stephen Dawson-Haggerty[2], Jay Taneja[2], Jorge Ortiz[2], David Culler[2]

[1]Lawrence Berkeley National Laboratory, Berkeley, California, USA
[2]University of California, Berkeley, USA

Abstract

Miscellaneous and electronic devices consume about one-third of the primary energy used in U.S. buildings, and their energy use is increasing faster than other end-uses. Despite the success of policies, such as Energy Star, that promote more efficient miscellaneous and electronic products, much remains to be done to address the energy use of these devices if we are to achieve our energy and carbon reduction goals. Developing efficiency strategies for these products depends on better data about their actual usage, but very few studies have collected field data on the long-term energy used by a large sample of devices due to the difficulty and expense of collecting device-level energy data.

This paper describes the development of an improved method for collecting device-level energy and power data using small, relatively inexpensive wireless power meters. These meters form a mesh network based on Internet standard protocols and can form networks of hundreds of metering points in a single building. Because the meters are relatively inexpensive and do not require manual data downloading, they can be left in the field for months or years to collect long time-series energy use data.

In addition to the metering technology, we also describe a field protocol used to collect comprehensive, robust data on the miscellaneous and electronic devices in a building. The paper presents sample results from several case study buildings, in which all the plug-in devices for several homes were metered, and a representative sample of several hundred plug-in devices in a commercial office building were metered for several months.

Key words: end-use metering, advanced meters, load research, wireless networking

Introduction and Motivation

Miscellaneous and electronic devices (also known as miscellaneous and electronic loads, or MELs) consume about one-third of the primary energy used in U.S. buildings, and their energy use is increasing faster than other end-uses [1]. Because the usage of these devices tends to be closely tied to the activities and lifestyles of a building's occupants, their energy use varies greatly between buildings and device types. In order to address the growing energy use of MELs, it is important to have empirical, field data on the energy use of these devices, for the purposes of policy development, product design and testing, and consumer information. These field data allow targeting energy efficiency activities at products that contribute the most to energy use, and also help guide the development of technologies to address the most consuming operational modes. Field data are also important for accurately measuring and verifying the savings from energy efficiency programs that address MELs products.

Previous Research

The most comprehensive studies of the MELs end-use in the U.S. are based on national surveys of a few thousand residential and commercial buildings, in which monthly, whole-building utility bills are collected. These monthly bills are then statistically disaggregated to estimate end-use energy consumption, using building characteristics, equipment ownership, and exogenous factors such as weather to explain variation in energy use. In these models, miscellaneous and electronic loads are included in the "Other" end-use, which is simply a statistical residual that cannot be attributed to one of the traditional end-uses (heating, cooling, lighting, etc.), and is therefore subject to errors due to data collection or model specification in these traditional end-uses. This type of whole-house metering has also been conducted in other countries, such as by Firth et al. [2] in the UK.

Another study approach is to use energy-consumption data from controlled, laboratory conditions, combined with shipment and stock data, to produce bottom-up estimates of MELs energy use by device type. These studies have been developed for the residential [3] and commercial [4] sectors in the U.S.

Starting in the 1980s, to avoid the uncertainties inherent in the whole-building disaggregation methods, U.S. electric utilities began conducting more detailed end-use metering studies to provide input data for load forecasting. This metering was typically conducted at the branch-circuit level in buildings, to identify large individual loads (e.g., furnaces). The largest such study was the End-Use Load and Consumer Assessment Program (ELCAP), conducted in the Pacific Northwest [5]. Other large-scale residential end-use metering studies have been conducted in northern California [6] and central Florida [7]. Similar residential studies have also been conducted in Europe [8] and New Zealand [9]. These studies typically monitored several hundred homes (ELCAP also monitored commercial buildings). Due to data storage and processing limitations, typically ten to fifteen circuits or devices were monitored in the homes and energy measurements were taken every ten to fifteen minutes. Depending on the study, monitoring lasted from one month to one year.

While these studies are still an important basis for our knowledge of energy use in buildings, they are best at identifying the consumption of large devices such as furnaces, water heaters, and refrigerators. With the proliferation of MELs over the last 20 years, a more intensive style of metering—at the individual device level—is needed to properly characterize energy use of this equipment. Several studies have been conducted in recent years to fill this gap. In California, MELs metering has been conducted in both residential [10] and commercial [11] buildings. The residential study sampled 50 homes, metering 17 devices per home, on average, for a period of one week. Meter readings were collected at one-minute intervals. The commercial building study sampled 47 office buildings, metering 10 devices per building, on average, for a period of two weeks. Meter readings were again collected at one-minute intervals. A third study of this type was recently completed in Minnesota. Detailed metering was conducted in about 50 homes, with 16 devices metered per home, on average, for a period of one month. Meter readings were collected at six-minute intervals (or 90-second intervals for computers). The data collected through these studies significantly improved the state of knowledge of MELs energy use in U.S. buildings. The main limitation is that the expense of the metering equipment (the last two studies used Watts Up Pro meters, www. wattsupmeters.com, which cost US$200-300 per metering point) limits the number of devices per building that can be metered. Because of the wide diversity of MELs devices found in buildings, it is important to be able to meter a large number of devices per building. Also, the meters all used on-board data storage, which limits the length of the metering period and the frequency of energy measurements.

Study Purpose

To address the limitations of these earlier studies, we felt it was important to develop MELs field metering techniques that are more cost-effective and allow more frequent meter readings over longer time periods. The goal of this study was to take advantage of recent developments in wireless sensor networks to develop a MELs field study methodology that was relatively low-cost, reliable, and allowed metering all the MELs devices in a home and a representative sample in a commercial building. The resulting methodology is tested in several homes and a commercial office building. Another goal of this study was to further refine field methods for conducting an inventory of MELs devices and, where devices are too numerous to meter all of them, develop a method for selecting devices to meter.

Wireless Meters and Network

The wireless power meters used in this study are a research platform developed by the University of California, Berkeley. Called ACme ("AC meter"), these meters provide data readings as frequently as every 10 seconds, are accurate to about 0.5% of the reading, and wirelessly transmit the data back to a central database. These meters are ideally suited to research applications because they are based on an open platform that can be improved and adapted for a given project [12, 13]. The ACme system consists of three tiers: the ACme node (Figure 1, and shown installed in Figure 2) which provides a metering interface to a single AC outlet, a network fabric which allows the meter data to be communicated over an Internet Protocol (IP) network, and application software that collects the power and energy data, stores it in a database, and provides various data processing functions. The architecture used in residential buildings is summarized in Figure 3. Commercial building installations use the same architecture, except the TED meter is not present and multiple edge routers are used for greater floor-area coverage.

Figure 1 – ACme node (scale in inches)

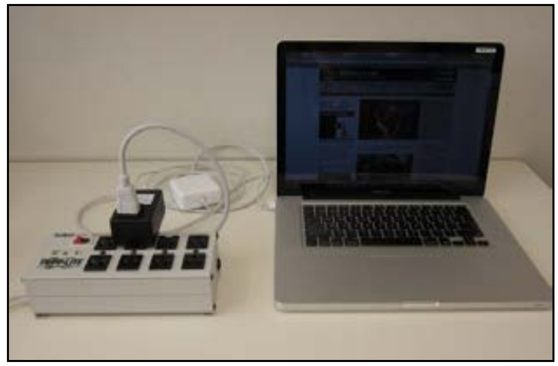


Figure 2 –ACme node (left), measuring laptop power

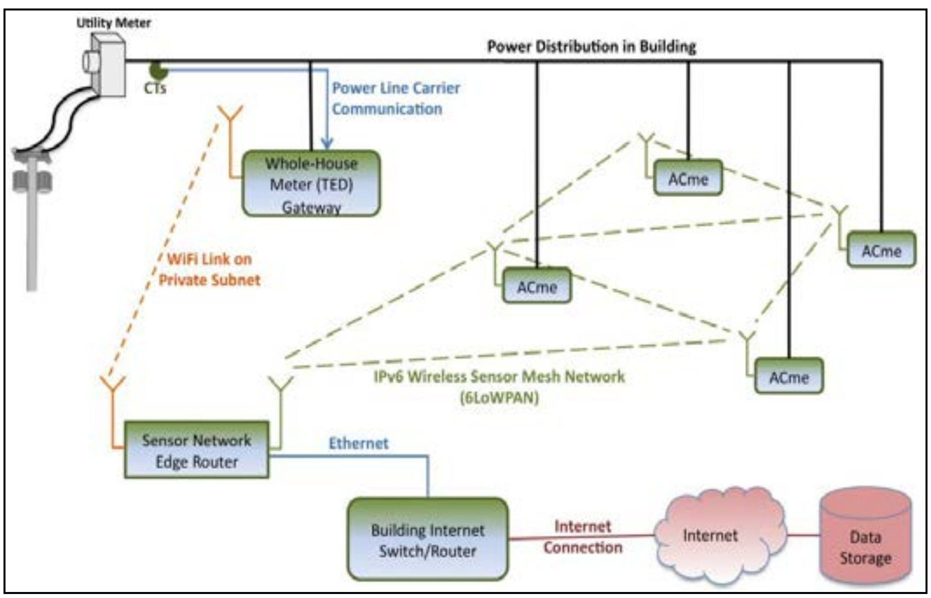


Figure 3 – Residential Metering Network Diagram

The ACme node integrates a wireless communications module with a dedicated energy metering IC to provide real, reactive, and apparent power measurements. The network comprises a complete IPv6 network stack on every node, based on the open-standard *6LoWPAN* network protocol and the *Hydro* routing protocol [14]. The nodes form a mesh network, in which they cooperatively route data packets through the network to an edge router, which provides bi-directional communication with other IP networks. The application tier receives and stores readings in a database and uses a web server for visualization. Nodes automatically join the IPv6 subnet after being plugged in, and begin interactions with the application layer. Due to the small size and use of commodity parts, the purchase cost of the ACme system is approximately $100 per node. The power draw of the ACme system is approximately 1W (constant) per node and a few watts per edge router, which sums to a few tens of watts for a residential installation and hundreds of watts for a commercial building. In addition to the ACme network for device-level metering, we also collect whole-building energy data to calculate the fraction of whole-building load due to MELs devices. In homes, we use a TED 5000 (www.theenergydetective.com) to collect whole-building data, as shown in Figure 3.

Commercial Building Deployment

The commercial study building, an office building located on the LBNL campus, is a 1960s era facility largely used as a traditional office space. It has a total floor area of 89,500 square feet, of which 62,100 square feet is considered net usable. Approximately 450 occupants in six working groups are located on four floors and a basement. The building has individual offices, cube farms, conference rooms, small kitchens or break rooms, a computer training facility, server closets, and network equipment.

MELS Device Inventory

We conducted a full inventory of the MELs devices in the office building. Although it may not be practical to do this in a larger building, we wanted a full inventory to serve as "ground truth" in comparing various sampling approaches.

Due to the diversity of devices, a standardized system of identifying and recording MELs is essential for inventory and energy data analysis. Nordman and Sanchez [15] developed a taxonomy of MELs for a California Energy Commission study, and we augmented this taxonomy by referencing other existing taxonomies (Energy Star product categories and California Energy Commission appliances list). The taxonomy consists of three levels - End Use, Category, and Product Type. MELs are divided into three major end uses – Electronics, Miscellaneous, and Traditional. Each end use is in turn composed of categories, and each category contains many product types. For example, a "LCD computer display" is a product type in the "Display" category, which is part of the end use "Electronics". During the study, we expanded and fine-tuned the taxonomy, in order to describe certain devices in a more consistent way and as we encountered new device types during the inventory.

In addition to the device taxonomy, information recorded during the inventory included:

- Location and space type, Date and time of inventory, Manufacturer of device;
- Any device specific information, such as diagonal screen size of displays and form factor of computers;
- If device appears to be in use, if device is plugged in, power state and portability of device.

Before conducting the extensive whole-building inventory, we explored different inventory methods, seeking a compromise between time and effort, quality and quantity of information gathered, compliance with building security requirements, and occupant disruption.

Occupant Consent and Access

For the purposes of our study, the building occupants who use and interact with the MELs devices are considered research subjects and therefore protected by "human subjects" rules imposed by the U.S. federal government. Some guidelines that we followed are general in nature, such as providing occupants with advanced notice before inventory and not identifying any personal information. Others are more specific, such as the prohibition of videotaping during inventory (to protect occupant privacy).

Much of the inventory was performed after work hours, in the absence of building occupants in order to minimize disruption. Because the research team works in the study building, after hour access to the building was made easier in most cases. For some workspaces however, an escort by a representative was required because of security concerns or in sensitive areas such as computer server rooms.

Inventory Data Collection Method

Based on our inventory of a small area, we projected that the building might have roughly 5,000 devices. With so many devices in place, we experimented with the following data collection methods before one was selected for deployment:

- Voice recording, with electronic voice recognition and transcription,
- Paper, with manual entry at a later time,
- Direct electronic entry (typing in spreadsheet) in real-time.

The voice recognition method appeared to be promising at first, as the voice recognition software used is able to instantly convert spoken language into text. Using a wireless headphone, the researcher identified and spoke the inventory information, while the software recorded data directly into a spreadsheet. We found several drawbacks to this approach: transcription accuracy varied depending on the position of the microphone and the individual, and training the software to recognize an individual's speech pattern can be time consuming and may not be practical if multiple personnel are involved in the inventory activities. For these reasons, this method was not considered further.

The paper method involves writing down information during the inventory and transcribing it to an electronic format afterwards. The inventory is best done by a two-person team, with one person identifying the MELs devices and reading out relevant data, while the other person records data by hand. A printed form to fill in during the inventory helps ensure consistent data collection. The written entry also takes relatively little time, however, manual entry adds significantly to the inventory effort.

The method we found best suited for the study building is the direct electronic entry method. The same two-person team would take the same roles as with the paper method. However, the data entry person would now enter data directly into a spreadsheet using a laptop computer, combining data entry and transcription in one task. In addition, given the long lists of MELs included in the taxonomy, we found that the built-in taxonomy lists set up in the spreadsheet greatly facilitate the process of consistently identifying and recording MELs.

Mobile Devices

Aside from the diversity of devices, another challenge that the study of MELs present is their mobility. Devices such as computer notebooks and small electronic devices are moved between locations, and since we performed the inventory after work hours some devices might have been taken home by the occupants. If the mobile devices were not present during our inventory, we looked for other signs of their presence in the workspace, such as notebook docks, external power supplies for notebooks and small electronics, and connection cables for external displays. If we believed that a mobile device might be present, we returned during work hours to confirm the presence with the occupant.

Meter Sampling Methodology

With close to 5,000 MELs in our study building, metering all these devices would be time and cost prohibitive, and not all data generated would provide useful insights. The original study goal was to install 500 ACme meters—which is about a 10% sampling rate—for a 3-6 month period to capture usage patterns and any seasonal variation. The selection of an appropriate sampling method is driven by the multi-fold purpose of our energy data collection and analysis:

- Measure power consumption of MELs and capture the different power states;
- Derive usage patterns of MELs;
- Study usage correlations between devices, i.e. computer, display, and lighting within the same occupant's office;
- Provide a large survey of power and energy measurements of individual MELs devices while in actual use.

We used a stratified random sampling approach to select devices for metering. Devices were divided into strata several ways – by Device Type, by Organization, and by Space Type – to meet our data collection objectives listed above. We also divided the building inventory into stages, and each of the five floors was considered a separate sampling stage. Staging allowed the field team to build the network sequentially to ensure wireless connectivity as meters were deployed. Phasing deployment on one floor at a time was also more time efficient.

The first stratification method we used was by device category or product type, in which devices that we expected to have more variation in power levels or usage (such as computers) were placed in their own strata. Some device categories were assigned to a strata that was not sampled at all, if they were a device that consumes a constant amount of power with an insignificant or predictable usage pattern. For these devices, such as power strips, surge protectors, or staplers, it is not essential to measure their power consumption for long periods of time. Instead, we spot metered them with wired power meters to measure their typical power use and inferred these power levels in actual use. There are also a small number of MELs in the study building that are hard-wired or rated at more than 15-amps, making them unsuitable for use with the ACme meters.

The next stratification method we used is by organization. The study building is occupied by several organizations within LBNL, and the types of MELs used and their usage patterns are likely to differ by the type of organization.

The final stratification method was by space type. Different space types may have very different MELs categories in use, and stratification by space type helps ensure that the types of devices within each strata are more homogenous. For example, workspaces mostly contain office equipment such as computers, displays, and lighting. Common spaces, i.e. office common or hallways, contain shared MELs such as copiers and printers, whereas conference and server rooms contain yet different device types.

In some cases, we used a combination of these stratification methods to select samples for metering, to ensure that the final sample of devices accurately represents the whole building. For example, the first floor of the study building is occupied by workers from 4 different organizations. In this space, we first stratified by space type, then by organization, according to the floor area occupied by each organization. We installed an average of four meters per randomly-selected office/cubicle, with priority assigned to computer, display, and imaging devices, in order to study usage correlation between devices. Remaining meters were randomly installed on device(s) in the offices/cubicles. For meters assigned to common spaces, we stratified by device category and product type, focusing on office and kitchen equipment.

Residential Building Deployment

For our residential study, we selected 3 homes for a full MELs inventory and metering, with the meters remaining in place for 6 months to capture seasonal variation of devices. Two of the study homes are typical existing homes located in Oakland, California, and the third is a zero-energy new home located in Boston, Massachusetts. The homes were selected using a questionnaire that identified a number of household characteristics preferred for the study, such as having a broadband wireless Internet connection (needed to transmit ACme data back to LBNL), number of household members, and the variety of MELs in the home.

Inventory

Once the study homes were selected, we made one site visit to conduct an interview and guided walk-through of the home with the homeowner, a whole-house MELs inventory, and ACme meter installation. During the interview with the homeowner, we explained details of our study, and asked questions about their usage of MELs and the location of any unused and stored MELs that they might overlook. The homeowner then showed us the location of their electric panel, rooms in the house, and both in-use and unused MELs. During the walkthrough, one member of the field team took the role of interviewing the homeowner, while the other researcher sketched diagrams of the rooms, recorded the locations and quantity of electrical outlets, and noted locations of MELs as described by the homeowner.

After the walk-through, the field team performed a full inventory of the MELs devices in the home while installing meters at the same time. In addition to the inventory methods considered for the commercial building, we also tested a video data collection method, in which the field team videotaped the MELs being inventoried and narrated relevant information for recording on the video. The recorded video was then transcribed into electronic record after the field visit. We found that videotaping in the field takes relatively little time, but the manual transcription afterwards makes the whole process time consuming. Therefore, we decided to use the same direct electronic entry method that we used for the office building.

Metering Methodology

Since we were interested in the fraction of energy use contributed by MELs, our goal was to install meters for all MELs that were in-use in the homes. We assigned 75-80 meters for each home. If the number of MELs in the home exceeded 80, the preference was to meter devices that were expected to be bigger energy users and/or have variable usage patterns. In some cases, we combined multiple similar loads, such as a cable modem and a network switch, for metering by a single ACme.

To capture the energy use of devices that are only periodically plugged in, we also installed meters on sockets that the homeowners indicated were used periodically but had no device plugged in during our visit. The homeowners were instructed to plug devices into a meter wherever possible. To identify these transient devices that are not plugged in at the time of our visit, we provided the homeowners with instructions and a log book to make an entry when they connect these devices to an available meter. We also provided homeowners with extra ACmes for use with any new or seasonal devices.

In addition, because we wanted to quantify the fraction of overall home energy consumption due to MELs, we installed a TED whole-house energy monitor in each home. This device contains current transformers that are installed in the home's electric panel and uses power-line carrier communication to transmit data to a gateway that communicates via WiFi to the ACme edge router for relay to LBNL via the homeowner's internet connection (as shown in Figure 3).

Methodological Findings

In addition to the study findings listed later, we have accumulated extensive lessons learned and experience from the inventory and metering activities that will be useful in future studies.

Building Sub-metering Data

A key question for MELs research and evaluations is what is the fraction of total building electricity used by MELs. As traditional building systems become more efficient, the fraction used by MELs will increase. In the office building, because of the incomplete building sub-metering data available, determining the MELs fraction of energy use proved to be difficult. When the building was first built, electrical panels were set up to serve distinct end uses, and MELs consumption in the building could be obtained by subtracting all the primary end-use consumptions (i.e. lighting, HVAC) from the whole-building load.

Over the years, however, as new services were added, multiple end-uses were extended from these single-voltage panels. In recent years, a sub-metering project has been launched for the building, and a large number of power meters and an extensive network reporting system were commissioned to measure energy consumption of each end use over time. But because of the highly intertwined end uses at the panel level, the MELs portion of energy consumption, which is obtained by measurement subtractions, is mixed in with small amounts of other end uses.

Electrical systems in buildings are continually changing to meet occupants' needs, and this phenomenon is probably not uncommon in buildings older than a few years. But this mixed end-use issue makes it difficult to obtain reliable sub-metering information in a building, and building managers are advised to avoid this if they expect to install a building metering system in the future.

Power Meters

Much of the metering equipment available in the market either has limited internal storage or requires connection to a computer for continuous data storage, making large-scale deployment labor-intensive and difficult. Power meters with wireless data transmission have recently become commercially available in a few form factors, such as plug meters or power strips. The ACme meters have several advantages over most commercially available meters that make them appropriate for large-scale deployment:

- Small form factor is unobtrusive and fits well into the building environment,
- In-house developed meters are less expensive than commercially available meters and allow flexibility for software and hardware upgrades and adjustments,
- Real-time data collection over a wireless network eliminates the need to manually download data and allows for real-time analysis,
- Relatively high sampling frequency of 10 seconds facilitates power-mode identification.

The ACmes also present some challenges:

- As a research platform the ACme system has not been as extensively tested as some commercial products, so is not as stable and reliable as one would like for a research study,
- Meeting Underwriters Laboratory (UL) safety standards takes substantial verification and testing,
- Managing the manufacturing, programming, testing, and calibration process for hundreds or thousands of measurement devices is time-consuming.

Preliminary Findings

Below we present our findings from the inventory and metering data we collected thus far in the study. Figure 4 presents the device distribution based on a full inventory in our commercial study building. The wide diversity of devices in the building is apparent from the number of device categories present. Moreover, the “Other” category contains 127 device types.

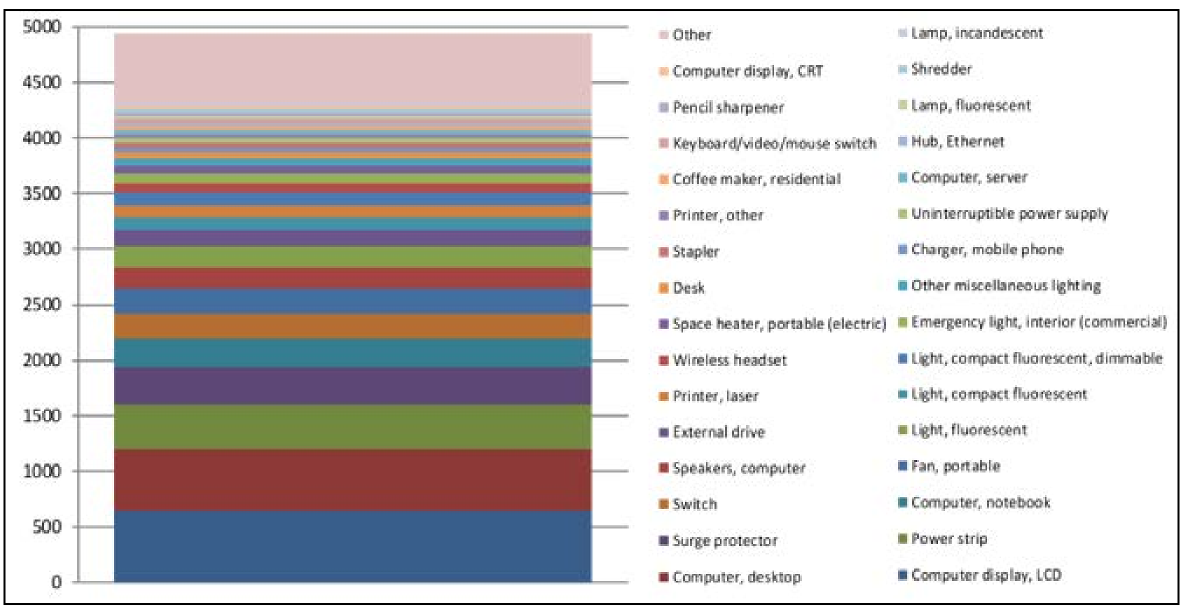


Figure 4 – MELs distribution in sample office building

An interesting use of the inventory and metering data is to compare the count and energy use between devices. Figure 5 presents the count of the top five energy users and all other devices, scaled with their respective energy usage in annual energy terms, for the commercial study building. Note that the annual energy consumption shown is based on a month of metering for the third floor of the building (the first to have a complete sample of meters installed). Energy estimates for the entire floor are projected from the metered sample of devices using sample probability weights. Computers use the most energy compared to their count in the building, whereas the "Other" devices show just the opposite. Because the building is mostly used as office space, displays, imaging, lighting, and networking are the next largest energy users. The energy breakdown shows that information technology equipment is the largest target for energy efficiency improvements.

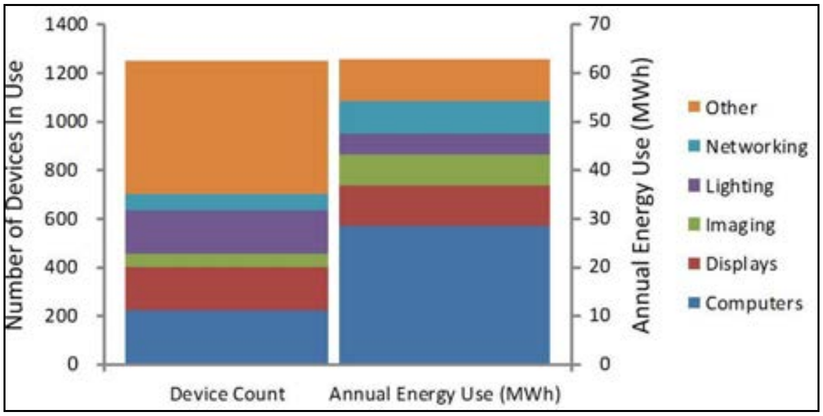


Figure 5 – Office building Device Count & Energy Use, 3rd floor

Figure 6 presents a similar plot, for one of the two study houses located in the San Francisco bay area, in which all plug-load devices are being monitored in real-time. In this home, plug lighting is the biggest energy using device category and also contributes to the highest count of devices. Just like the commercial building, computers consume a large amount of energy relative to their saturation. Other device types that dominate this particular home are entertainment, appliances, and kitchen devices.

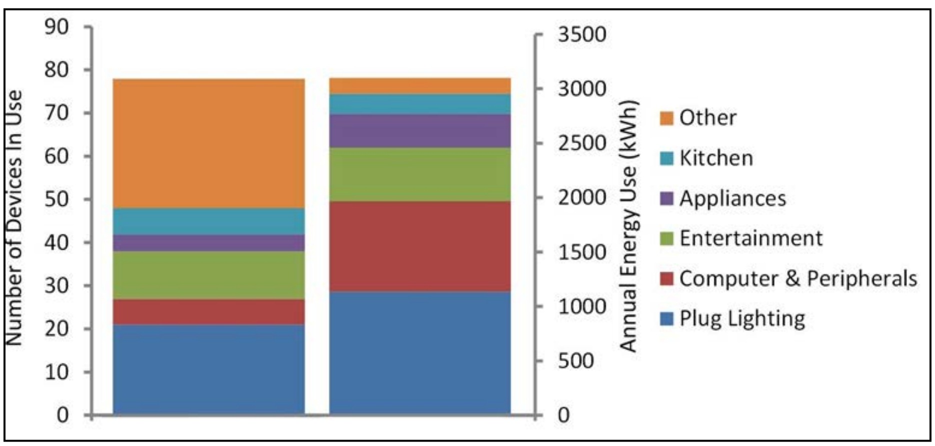


Figure 6 – Residential device count and energy use, Home #2

Figure 7 shows the high degree of power mode variation between typical office computers in the commercial study building. Some computers were never used during the week in question while others were left on almost the entire time as shown in the left hand chart. The right chart shows that energy use is dominated by time in the "on" (active) mode, even when time in that mode is small—computers with even relatively small on times consumed most of their energy in the on mode. Therefore, increasing device sleep time will be an effective means of improving energy efficiency for devices that are not routinely turned off. Computers that are left on 6-10 hours per day vary in typical energy use by almost ten times. Improving the on-state efficiency of devices will also be an effective means of reducing energy use. These findings are shown for computers, but they apply to other devices in this building as well.

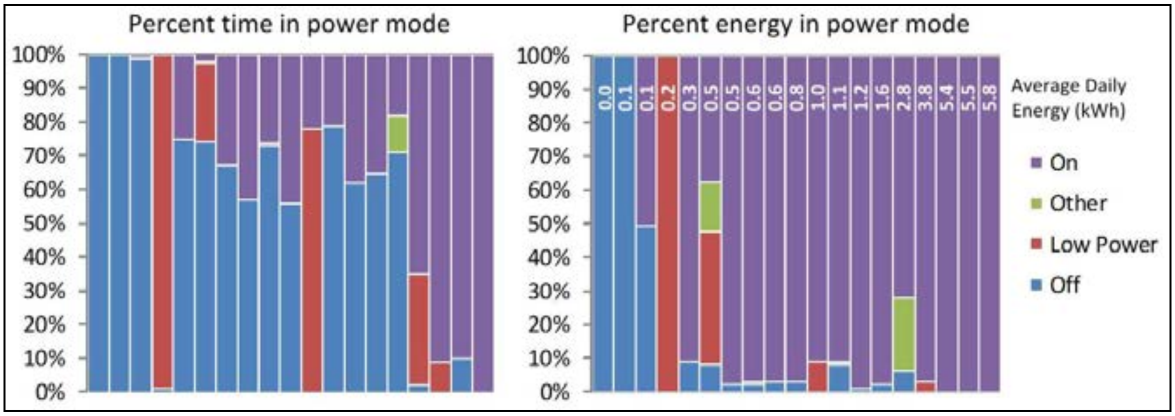


Figure 7 - Percent time and energy in power modes for 19 computers metered over a workweek in office building. Each column represents an individual computer, sorted from left to right by increasing energy use. Device ordering is the same in both charts.

MELs load shapes are useful to improve load modeling in new or retrofit designs and to improve utility forecasts for peak load or demand response planning. We expect that load shapes for some devices will have seasonal dependencies. For example, space heaters may be used more during the winter in some buildings but more in the summer (to prevent overcooling) in others. Figure 8 shows the average weekday power consumption for computers in the office building, with a one-minute sampling period. The light traces represent the average consumption of the individual computers. From this figure, we see that there is a great deal of variation from device to device and significant usage during off-hours, but the average load shape reflects the most common building occupancy periods.

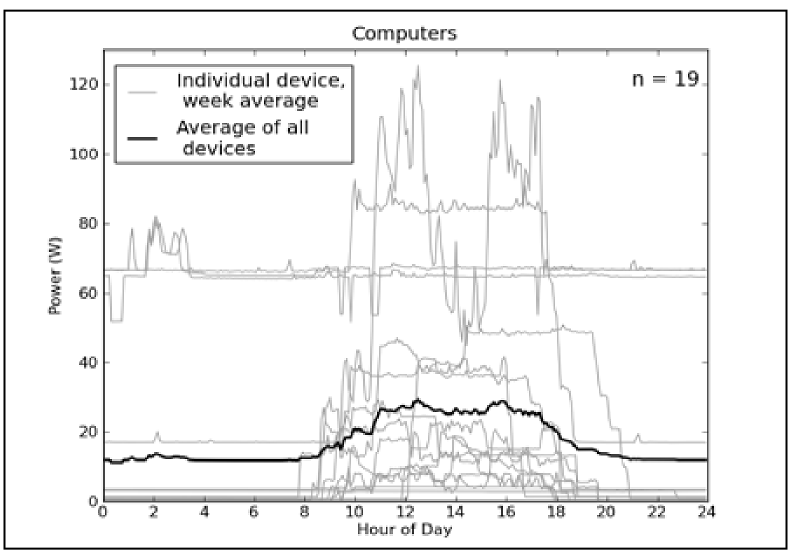


Figure 8 - Weekday average power consumption for computers in office building

Future Work

Further refinement of study methods and protocols. To improve the value of the field data collected, it would be useful to collect additional data beyond just energy and power, for example, occupancy monitoring to assess opportunities for energy savings. It also would be very helpful to develop reliable methods to identify and meter devices that move between power outlets in the building.

Expanded data collection. Due to the small number of buildings in this study, it is necessary to meter additional building types, sizes, and vintages, in order to make the results more representative of the building population.

Improved metering technology. The ACme metering platform provides a cost-effective way to deploy large-scale energy measurements and also offers an open platform for software upgrades and network controls. However, further development of the platform is needed for easier deployment and management, improved communication reliability, and lower-cost hardware (we estimate that the hardware cost could be cut in half with modest design changes). For permanent, non-research installations of wireless metering (or if integral to products), lower power-use metering hardware would help mitigate the direct energy use of the metering system. In addition, for situations where devices cannot be unplugged (as with servers or medical equipment), a non-intrusive power meter that could be clamped onto the power cord would be very useful.

MELs Product Development. Using real-time wireless sensors simply for monitoring baseline conditions is useful, but misses a lot of the potential of this technology. The monitoring and communication capabilities inherent in the ACme platform could be easily extended to provide MELs device management and control for the purpose of improving energy efficiency. Ultimately, power sensing and communication need to be built into all devices to enable this type of functionality and allow devices to cooperatively manage their power state to minimize energy use.

Summary

Unlike appliances in traditional end uses, the diversity of plug-in devices has made it difficult for policy makers to apply uniform standards to reduce their energy use. As efficiency improvements in the traditional end uses become more and more successful, plug-in devices will continue to increase their share of energy use in buildings. To develop effective strategies to reduce MELs energy use, large-scale data collection is needed to understand the areas of improvement available. The development of power meters with wireless mesh-networking technology (using the ACme system) has made large-scale data collection possible in a cost-effective way. The relatively high measurement accuracy and sampling frequency permit new types of analysis, such as accurate power-mode identification and approximate device-type identification.

Although our metering effort is still ongoing, the data generated thus far has provided valuable insight about the inventory, usage patterns, and device correlations for MELs in the residential and commercial buildings studied. Moreover, the collected data has informed the data collection strategies and meter specifications needed to improve our understanding of MELs. For example, from the collected data, we learned that a sampling frequency of no longer than 1 minute is needed in order to capture the rapid change in power mode in some devices, and a prolonged metering period is needed to understand device usage pattern and seasonal variation. In addition, due to the diversity of models for some device types such as computers, a large sample is needed for results representative of the entire product type.

Since the ACme meters are developed using an open platform, the meters and their mesh network are highly adaptable to meet research and individual project needs. In the future, improvements to the stablility and usability of the ACme system, new form factors, and the integration of occupancy sensing would be useful additions to improve future MELs studies.

References

[1] US DOE. *2009 Buildings Energy Databook*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009. Download at: http://buildingsdatabook.eere.energy.gov/.

[2] Firth S., Lomas K., Wright A. and Wall R. *Identifying trends in the use of domestic appliances from household electricity consumption measurements*. Energy and Buildings. Vol. 40. 2008. pp. 926–936.

[3] Roth K., McKenney K., Ponoum R. and Paetsch C. *Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential*. TIAX LLC, TIAX Reference No. D0370, 2007.

[4] McKenney K., Guernsey M., Ponoum R. and Rosenfeld J. *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type*.

TIAX LLC, 2010. Download at: http://zeroenergycbc.org/pdf/2010-05-26%20TIAX%20CMELs%20Final%20Report.pdf.

[5] Pratt R.G., Williamson M.A., Richman E.E. and Miller N.E. *Commercial Equipment Loads End-Use Load and Consumer Assessment Program (ELCAP)*. Prepared by the Pacific Northwest Laboratory for the Bonneville Power Administration, DOE/BP-13795-24, 1990.

[6] Brodsky J.B. and McNicoll S.E. *Residential Appliance Load Study 1985–1986*. Pacific Gas and Electric Company, 1987.

[7] Parker D. *Research highlights from a large scale residential monitoring study in a hot climate*. Energy and Buildings. Vol. 35, No. 9. 2003. pp. 863-876.

[8] Sidler O. *DSM: major findings of an end-use metering campaign in 400 households of four European countries*. Proc. of the ECEEE 2003 Summer Study. (Saint-Raphaël, France, 2-7 June, 2003). Ed.: ECEEE, Download at: http://www.eceee.org/conference_proceedings/eceee/2003c/Panel_2/2168sidler/Paper/.

[9] Isaacs N., Camilleri M., Burrough L., Pollard A., Saville-Smith K., Fraser R., Rossouw P. and Jowett J. *Energy Use in New Zealand Households: Final Report on the Household Energy End-use Project (HEEP)*. BRANZ Ltd., SR 221, 2010. Download at: http://www.branz.co.nz/cms_show_download.php?id=a9f5f2812c5d7d3d53fdaba15f2c14d591749353.

[10] Porter S.F., Moorefield L. and May-Ostendorp P. *Final Field Research Report: California Plug-Load Metering Study*. Ecos Consulting, 2006. Download at: http://www.efficientproducts.org/documents/Plug_Loads_CA_Field_Research_Report_Ecos_2006.pdf.

[11] Moorefield L., Frazer B. and Bendt P. *Office Plug Load Field Monitoring Report*. Ecos Consulting, 2008. Download at: http://www.efficientproducts.org/reports/plugload/Ecos-Office-Plug-Load-Report_14Jul2009_DRAFT.pdf.

[12] Jiang X., Ly M.V., Taneja J., Dutta P. and Culler D. *Experiences with a High-Fidelity Wireless Building Energy Auditing Network*. Proc. of the Seventh ACM Conference on Embedded Networked Sensor Systems (SenSys'09). (Berkeley, CA, Nov. 4-6, 2009). Ed.: Association for Computing Machinery (ACM), Download at: http://buzzing.cs.berkeley.edu/~xjiang/papers/jiang09sensys.pdf.

[13] Jiang X., Dawson-Haggerty S., Dutta P. and Culler D. *Design and Implementation of a High-Fidelity AC Metering Network*. Proc. of the The 8th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN'09) Track on Sensor Platforms, Tools, and Design Methods (SPOTS '09). (San Francisco, CA, April 15–18, 2009). Ed.: Association of Computing Machinery, Download at: http://buzzing.cs.berkeley.edu/~xjiang/papers/jiang09acme.pdf.

[14] Dawson-Haggerty S. *Design, Implementation, and Evaluation of an Embedded IPv6 Stack*, Masters thesis, Computer Science – Electrical Engineering and Computer Sciences, University of California, Berkeley, 2010. Download at: http://www.eecs.berkeley.edu/~stevedh/pubs/mthesis.pdf.

[15] Nordman B. and Sanchez M. *Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products*. Proc. of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings. (Asilomar, CA, August, 2006). Ed.: American Council for an Energy Efficient Economy, Washington, DC.

Nonintrusive appliance load monitoring (NIALM) for energy control in residential buildings

Michael Zeifman, Craig Akers, Kurt Roth

Fraunhofer Center for Sustainable Energy Systems

Abstract

Significant saving in energy consumption can be achieved by better energy management and control in residential buildings. More advanced control approaches require real-time information on the appliances in use. A straightforward method to obtain this information uses a power sensor attached to each household appliance of interest. Unfortunately, this method is costly and requires significant installation and maintenance efforts. A more sophisticated way to obtain appliance-specific data is by disaggregation of total power consumption data acquired at the main breaker level. Such nonintrusive appliance load monitoring (NIALM) uses a single point of power measurement (e.g., of the electric feed for the whole house), combined with special signal processing techniques.

Our paper presents overviews and test results for two novel NIALM approaches we are developing and testing. The first system uses an inexpensive off-the-shelf sensor (TED – The Energy Detective) to obtain real power data at a 1 Hz sampling rate. A statistical algorithm, optimally implementing historical data on power draws and power consumption patterns, has been developed for this system. The algorithm is capable of semi-automatic detection of major household appliances and outperforms the known NIALM algorithms in terms of detection accuracy. The second system relies on a custom-built sensor capable of sampling voltage and current at a rate of up to 100 kHz. At this sampling rate, voltage and current waveforms and their features are used to identify and track a much broader range of household appliances.

1. Introduction

Recent studies indicate that providing a consumer with a continuous feedback on the household appliance-specific power draw can lead to significant energy saving [1]-[6]. Such feedback can be based on continuous monitoring of household appliances. By attaching a sensor or a communication device to each appliance, it is possible to collect and disseminate the power-draw information in near real time [7]. Coupled with the Smart Grid, these “smartened” appliances could also be used in home automation networks [7]. However, as van Elburg pointed out, this option is “relatively expensive and complicated to supply” [4]. Moreover, many customers object to the modification of household appliances and home automation networks [7].

A nonintrusive appliance load monitoring (NIALM) method that uses a single point of power measurement (e.g., the electric feed for the whole house) can enable an alternative feedback option. Such a method requires both hardware (a sensor) and software (signal processing algorithms) components. The software component of NIALM depends on the hardware implementation. For example, signal waveform analysis can be used if the sensor samples voltage and current at a rate of at least several kHz. However, such sensors are still expensive and less available. An inexpensive and easy-to-install hardware alternative is a sensor that measures the total electric power in a residential unit at a sampling frequency of about 1 Hz.

We have conducted an extensive review of the existent NIALM systems and algorithms [8] and concluded that (i) existent NIALM methods are either not robust or provide marginal accuracy (~80%), and (ii) potential improvement can be achieved by using additional information and/or by combining several different methods. In this paper, we have applied these conclusions in two different sets of algorithms. In the first algorithmic set, we use statistics of time on, time off and power surge to complement the information on the power changes. This set is suitable for the low-frequency sensors. In the second set, we optimally combine two different algorithms that utilize signal waveform features. This set is intended for the high-frequency sensors.

The paper is organized as follows. Section 2 gives a brief overview of a NIALM system. The NIALM method we developed for a low-frequency sensor is presented in Section 3. By using simulation examples, we demonstrate that this method has the potential to outperform existent methods. In Section 4, we present our NIALM method for high-frequency sensors. The method combines together a multivariate statistical technique and a pattern recognition technique. The method is tested using our laboratory system. The two developed NIALM methods can be combined together in the future work, which is briefly discussed in Section 5.

2. NIALM Overview

The main idea of NIALM is to obtain appliance-specific information nonintrusively. The information is collected at the main breaker level (or at a circuit breaker level), and then disaggregated to obtain operational time and power draw information. Figure 1 shows an example of an aggregated power signal and the corresponding NIALM solution. In this illustration, the reconstructed operational time of e.g., a TV, is from 7:20 AM to about 8:30 AM, and the power draw is about 300 W.

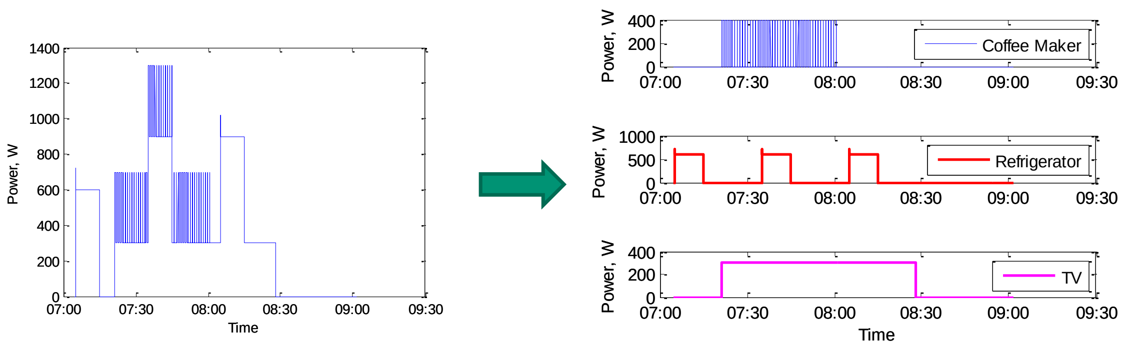


Figure 1. NIALM disaggregates an overall signal (left) into the loads on individual appliances.

In this illustrative example, the appliances are modeled as on/off appliances that consume constant power at a single steady state. In reality, coffeemaker loads depend on the water volume, TV power draw often follows the volume/brightness levels, and refrigerators have a second power state corresponding to defrosting. To encompass the variability in appliances' power draw patterns, the following four groups are suggested [9]:

1. **Permanent consumer devices**. Consumer devices that remain on for 24 hours a day, 7 days a week, with approximately constant active and reactive power draw. Examples of devices in this category include hard-wired smoke alarms and some external power supplies.

2. **On-off appliances**. Most household appliances, such as a toaster, light bulb, or water pump belong to this category.

3. **Finite state machines (FSM) or multistate devices**. This category includes consumer devices that pass through several definite switching states, whereby the complete switching cycle is repeated frequently in the daily or weekly cycle of events. Examples of FSM are a washing machine or clothes dryer.

4. **Continuously variable consumer devices**. Consumer devices with variable power draw, with no any periodic pattern of changing the states or power. Examples of such appliances include dimmer lights and power tools.

The NIALM example shown in Figure 1 is related to the low-frequency sensors that sample real and/or reactive power components. The underlying NIALM algorithms can only implement "macroscopic" signal features, e.g., changes in power draw. As such, the group of NIALM algorithms that utilize the low-frequency sensor signals is successful with on-off appliances that have significantly different power draws at the steady state. Use of the "microscopic" features of signals obtained with the high-frequency sensors can potentially help detect other groups of appliances.

3. NIALM Method for low sampling rate

Inexpensive and easy to install energy monitoring systems such as, e.g., the Energy Detective (TED) [10] and the corresponding Google Power Meter [11] can be used for NIALM. TED (see Figure 2) can record the real power and voltage at 1 Hz frequency and the Power Meter can display this information over the Internet. NIALM algorithms suitable for such a sensor have been detailed in several publications [9], [12]-[15]. These algorithms detect step changes in power and match these changes with the appliances being turned on or off.

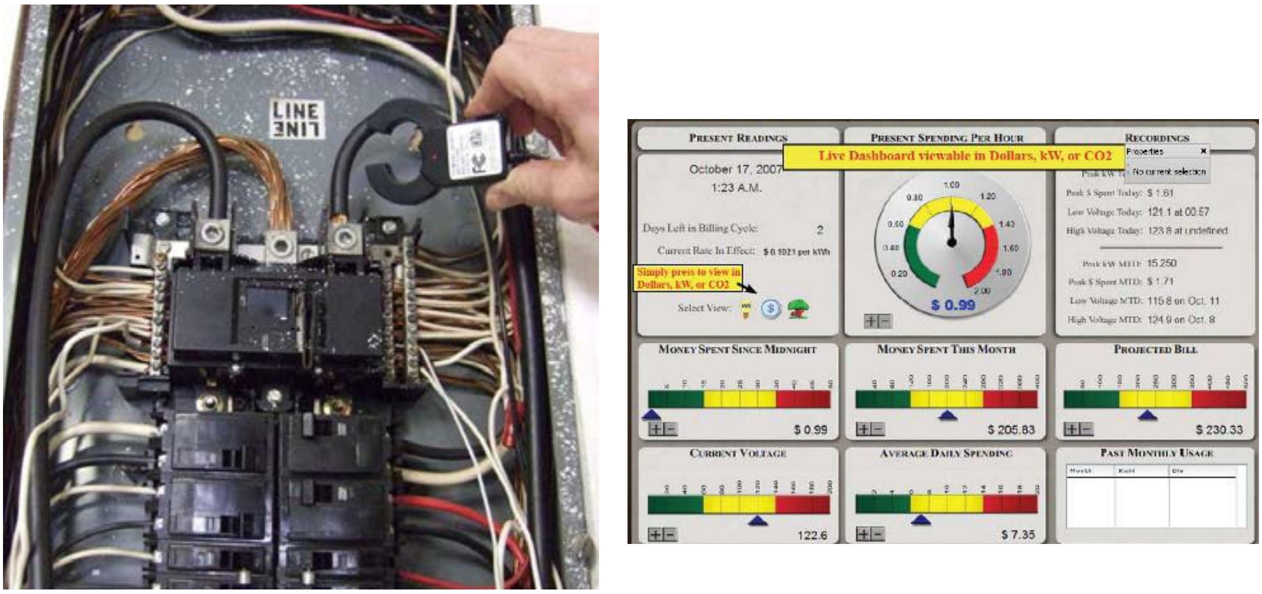


Figure 2. The Energy Detective (TED). Left: Current transformer of TED. Right: TED dashboard. From [10].

Even though these NIALM algorithms are capable of monitoring major household appliances, their accuracy level is of the order of 80%. The main reason for this marginal monitoring accuracy is an overlap in the power draw between different appliances. For example, the power draw of a computer monitor could equal that of an incandescent bulb, which makes these two appliances undistinguishable for the mentioned algorithms.

Our NIALM algorithm can overcome this challenge. There are three main novelties in our algorithm. First, not only power changes but also power surges (statistics of surge amplitude and duration) and their statistical distributions are used in order to better segment the appliances. Second, statistics of time of use (in terms of both duration and time of day) are included for better appliance separation. Third, the matching between the measurable power observations and the appliances is made by considering a series of transitions among the appliance states that maximizes the likelihood of not only the given series of power changes but also the time-of-use statistics and power surge statistics.

The algorithm is explained in detail elsewhere [16]. Here, we provide a brief overview. Figure 3 shows power-related features we use in the algorithm. The statistics of these features can be obtained by collecting and analyzing historical data. Similarly, the time duration statistics, i.e., the distributions of time on and time off for appliances can also be obtained. A combined cluster and statistical analysis is implemented in order to split the distributions that apparently involve more than one appliance or to merge the distributions corresponding to the same appliance. These analyses are continuously updated as new data are collected.

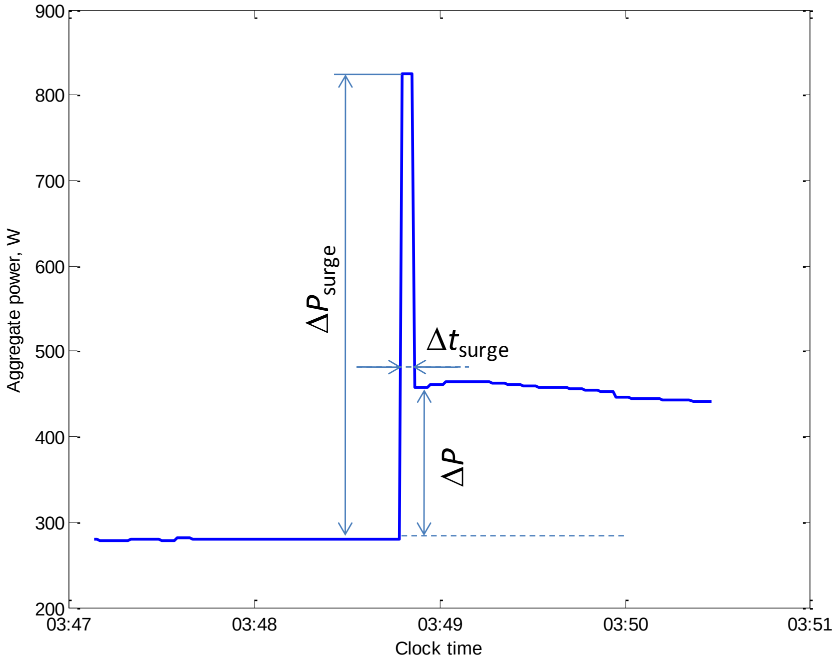


Figure 3. Power-related features: ΔP_{surge} is the power surge amplitude, ΔP is the change of steady-state power and Δt_{surge} is the surge duration in time.

Once the main appliances in a household are identified and characterized by the historical data, the main algorithm can process the new data by calculating the most likely path of appliance state changes (i.e., transitions) over time. We realize this by a Viterbi-type algorithm. Since the common Viterbi algorithm considers all possible transitions within a system, the system size (in our case, this equals the number of appliances in a household) renders a common Viterbi algorithm not amenable for computation. We have overcome this challenge by considering pairs of appliances with similar power draw. The resultant Viterbi algorithm with Sparse Transitions (VAST) has a computational complexity that is linearly proportional to the number of appliances, whereas a common Viterbi algorithm's complexity would exponentially grow with the number of appliances.

Figure 4 shows a principal block-scheme of our algorithm. The algorithm uses sensor measurements to calculate candidate times on and off. Subsequently, all these data are used by the algorithm to calculate the likeliest transition path, using the transition probabilities that are estimated by the prior statistics. These statistics are continuously updated by the new data.

We expect our algorithm to perform better than other algorithms for appliances with overlapping power draw. To test its performance, we consider simulated data on two appliances with a heavy overlap between the power draws [16]. The simulation data include 300 positive and 300 negative changes of power accumulated over 10 hours of sampling with 1 Hz frequency for two such appliances. The distributions of the power draw of the two appliances are Gaussian with means of 130W and 150 W for positive power changes and of -135W and -160W for negative power changes and standard deviations of 15W and 20W respectively. The distributions of time-on durations are uniform with boundaries of 30s and 80s for the first appliance and of 60 s and 100 s for the second appliance. Figure 5 plots the probability density functions (PDF) of the power draw, and clearly shows the heavy overlap in power draw between the appliances.

Figure 6 displays a fragment of the data generated along with the indication of appliance states. The indicator takes value 1 if appliance 1 is turned on, value 2 if appliance 2 is turned on, value -1 if appliance 1 is turned off, and value -2 if appliance 2 is turned off. Clearly, the heavy overlap between the power draws of the two appliances makes the reconstruction of appliance states a challenging problem.

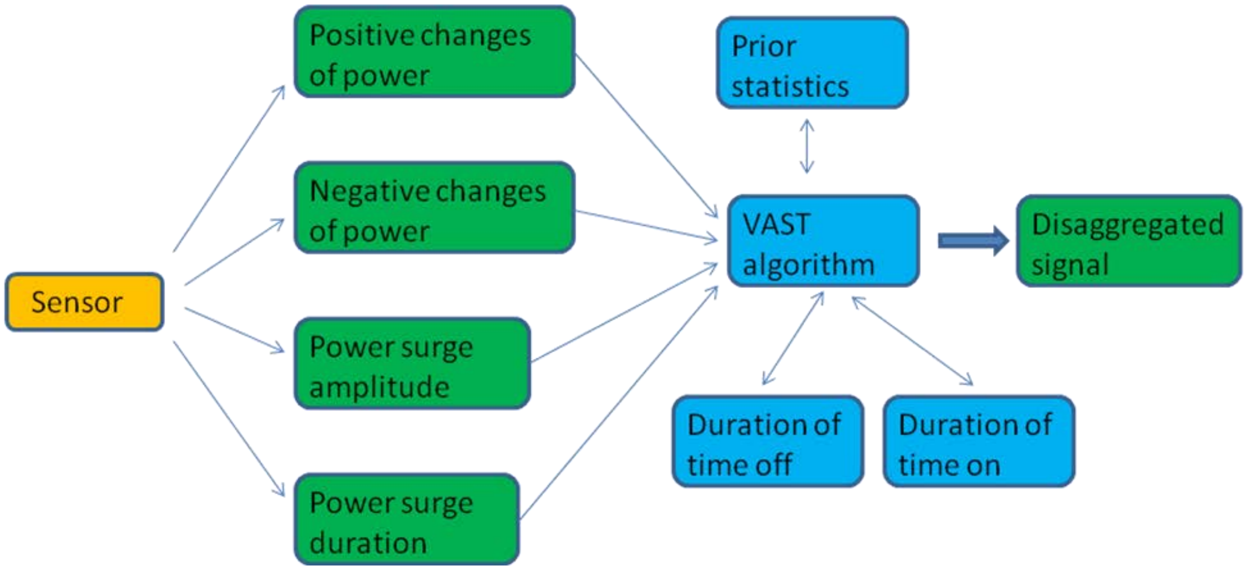


Figure 4. Block-scheme of our algorithm

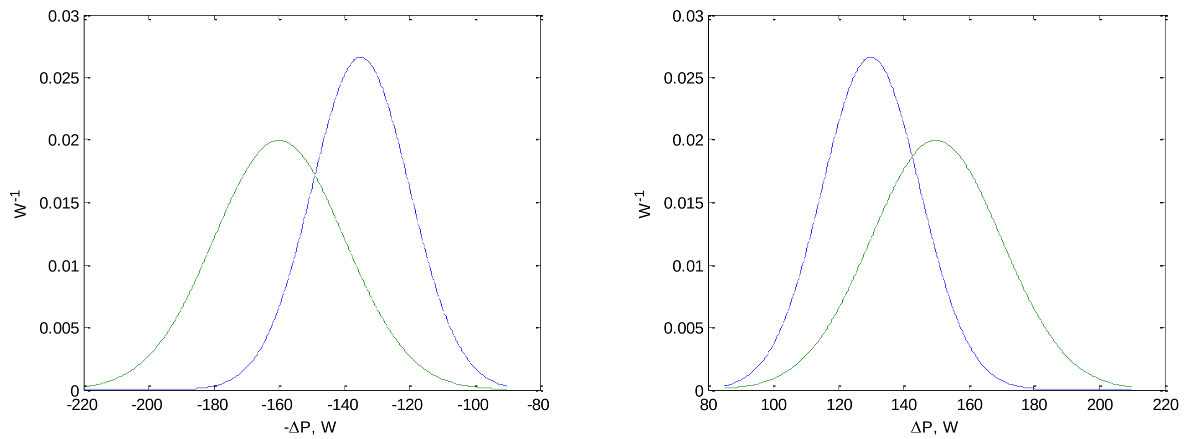


Figure 5. PDFs of negative (left) and positive (right) changes of power used in simulation of two appliances. From [16]. © 2011 IEEE

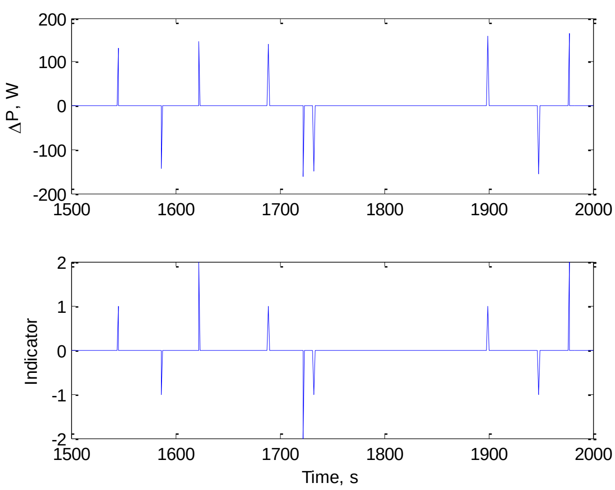


Figure 6. Fragment of simulated data. Total data set includes 600 power changes over 10 hours. From [16]. © 2011 IEEE

Firstly, we apply a common NIALM algorithm [9] to the simulated data. Portion of the results that correspond to the data fragment of Figure 6 are shown in Figure 7. The indicator takes value 0 whenever no matching between the positive and negative power changes of the same appliance can be found. It is seen in the Figure that the common algorithm performs poorly. The overall fraction of correctly reconstructed appliance states is 54.5%.

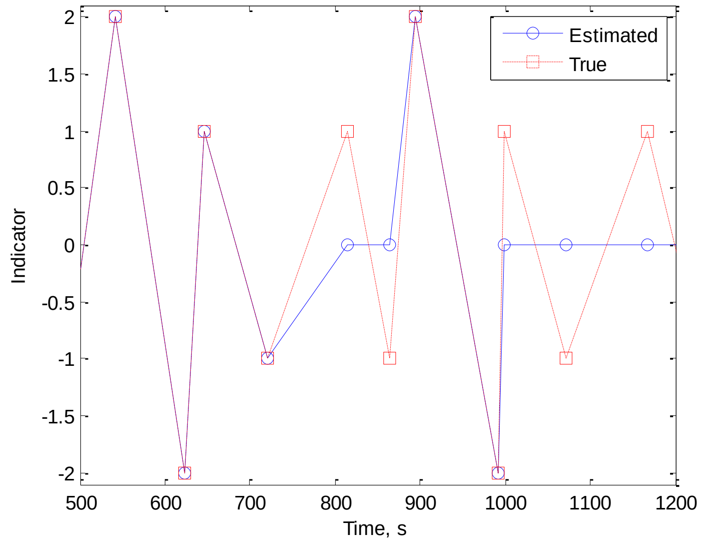


Figure 7. Fragment of results of established NIALM algorithm, applied to simulation data. Overall correct reconstruction is 54.5%. From [16]. © 2011 IEEE

The results of our VAST algorithm, applied to the simulated data, are shown in Figure 8. This particular portion of results indicates a perfect restoration of the appliance states. The overall fraction of correctly reconstructed appliance states for the proposed algorithm is 97.3%. This is a dramatic improvement over the conventional method.

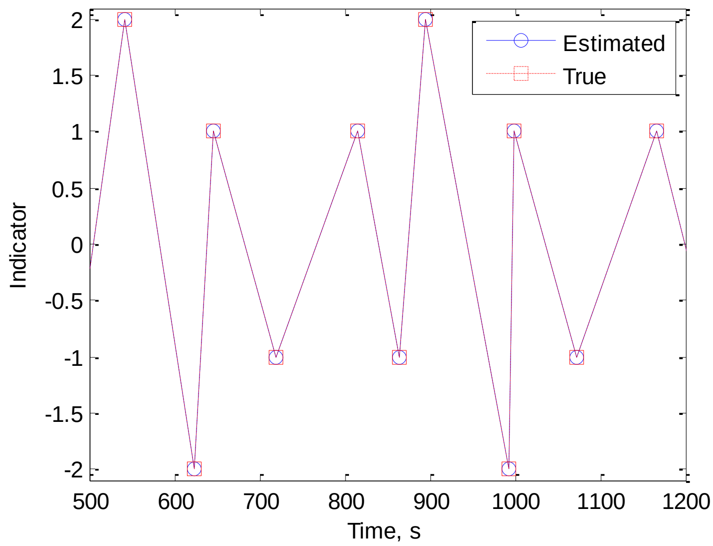


Figure 8. Fragment of results of our VAST algorithm, applied to simulation data. Overall correct reconstruction is 97.3%. From [16]. © 2011 IEEE

4. NIALM Method for high sampling rate

Signals sampled with a rate of more than several kHz can be used for waveform characterization. The use of waveform "microscopic" features can improve NIALM accuracy. In fact, the reported accuracy of NIALM methods based on high-frequency sampled signal is of the order of 90% [8]. Further improvement of accuracy can be achieved by combining two or more different methods based on different features [8]. In this Section, we describe our experimental data acquisition system and a proposed set of two combined algorithms for NIALM.

4.1 Data Acquisition System

Based on the results of the literature review [8], we decided to start exploring high-frequency NIALM with a sampling rate of 500 kHz. At these high sampling rates, data transfer and storage pose a challenge, since the data file size reaches tens of MB even during a 1s sampling period. Since the appliances need to be characterized not only in a steady-state regime but also in transitions from one regime, e.g., standby, to another regime, e.g., power on, there is a need to automatically identify such transitions and record the data accordingly.

The above challenges have been overcome in the system we call the iMEL-C (Individual Miscellaneous Electric Load Characterization System). The iMEL-C consists of a Data Acquisition device, a signal interface device, and software that runs on a Windows based laptop computer. The selected Data Acquisition (DAQ) device is the National Instruments USB-6251. It is an externally powered, USB DAQ device with 16bit resolution, multiple input ranges and a maximum sampling rate of 1MHz (aggregate) while sampling multiple channels.

The Signal Interface consists of current censors, a voltage sensor (voltage divider), a power supply for the current sensors, fuses, a devise under test (DUT) power switch and an enclosure. Figure 9 shows a photograph of iMEL-C, an explanation of the PCB layout follows.

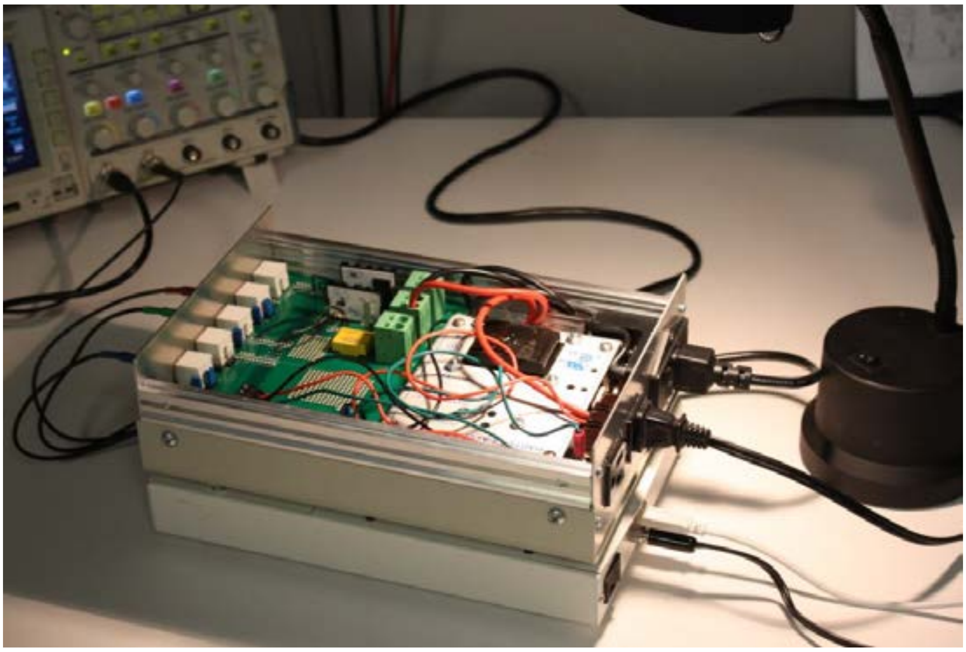


Figure 9. iMEL-C system for data acquisition

Voltage Sensor:

The voltage sensor consists of a voltage divider made of a 100kOhm resistor and a 1kOhm resistor. The measured reduction factor from the voltage divider is 0.982%. The DAQ system differential input impedance paths are significantly higher (rated at 10GOhm from input to DAQ ground) so no appreciable error is introduced through the DAQ. The voltage divider is jumper configurable between Load and Neutral, Load and Ground, or Neutral and Ground.

The voltage sensor circuit is independently fused with a fast-acting low current fuse, in case of a short in the system.

Current Sensor:

The iMEL-C system has three current sensors: one F.W. Bell NT-5 Magneto-Resistive Sensor, one F.W. Bell NT-15 Magneto-Resistive Sensor, and one Sensitec CDS4015 Magneto-Resistive Sensor. Although we performed tests with each sensor, we used the NT-15 for the 500kHz high frequency load characterizations because it has a good current range, over current protection, and good sensitivity at low currents.

Signal Interface:

The signal interface device consists of an enclosure that houses the electronic components of the system. It includes a linear (low ripple) DC power supply, to power the current sensors, a standard outlet receptacle, to plug electric devices into, a power switch with two fuses (one for the power supply, and one for the voltage sensor circuit), and a custom PCB containing the interface circuits for the voltage and current sensors, and additional circuits for grounding and isolation options of the output signals, to ensure a proper interface to the DAQ device. The PCB also includes expansion sites to accommodate further potential circuit configurations, such as notch filters or low pass filters.

4.2 Algorithms and results

Our high-frequency algorithms are based on the detection of transients in the waveform. Whenever the system observes a statistically significant change in the waveform, it records several waveforms before and after the change. It obtains the waveform of an appliance that apparently changed its state by subtracting the waveform before the change from that after the change. Figure 10 shows typical waveforms obtained in this way. Note that the waveforms are noisy and quite variable due to different appliance states. Note also that a waveform of Luminaire lamp (panel C on Figure 11) can be very close to that of the fan (panel D).

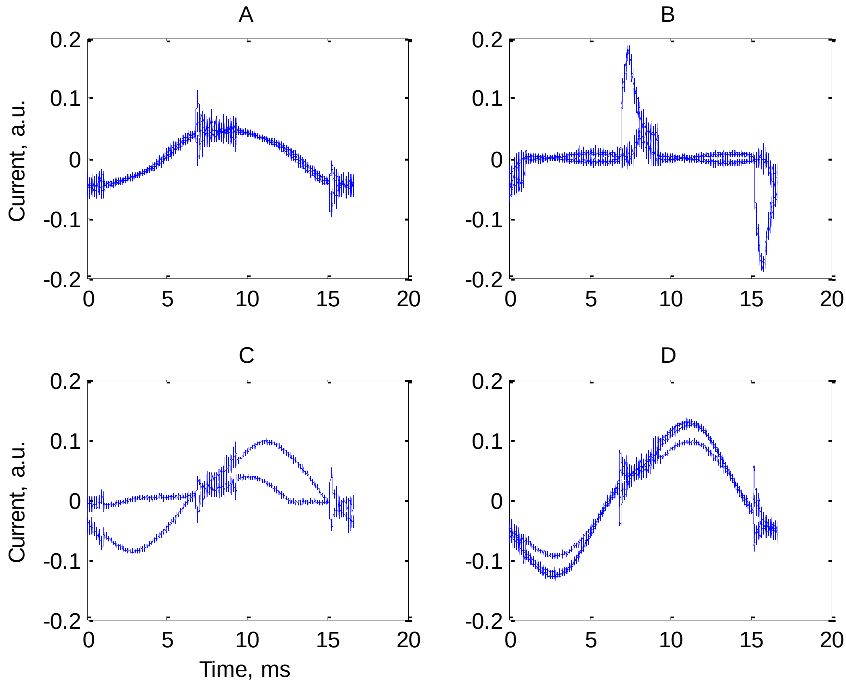


Figure 10. Waveforms of CFL lamp (A), CRT TV (B), incandescent special lamp Luminaire (C) and fan (D) in different setting. The waveforms are obtained by subtraction of a steady-state waveform before and after a transient detection. The transient can be either turning on or off.

Our two algorithms use waveform harmonics and a multivariate technique based on an unprocessed waveform. To combine these algorithms together, we implemented a probabilistic setting for each. In this setting, a PDF underlying an algorithm is calculated for an experimental waveform using previously obtained PDF-s for waveforms of all appliances. The experimental waveform is then classified based on the maximum PDF value.

This approach is illustrated in Figures 11 and 12. We used a sequence of 17 transitions (on/off) among the four appliances and calculated a PDF value for each experimental waveform on the basis of the PDF-s of the four appliances. In this way, we obtained 68 PDF values, four for each transition. The appliance state is then reconstructed using the maximum PDF value for each of the 17 transitions. It can be observed that algorithm based on waveform harmonics produces one wrong classification whereas the multivariate statistical technique perfectly classifies the appliances.

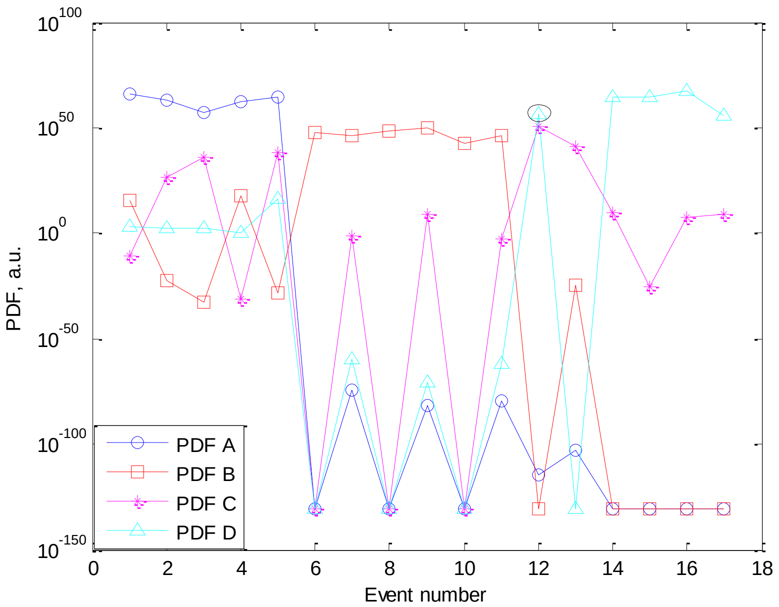


Figure 11. PDF-s corresponding to our algorithm that is based on waveform harmonics, the classification is based on the maximum PDF value for each event. The actual event sequence is: A (1-5), B (6-11), C (12-13) and D (14-17). The wrong classification for event 12 is marked with an ellipse.

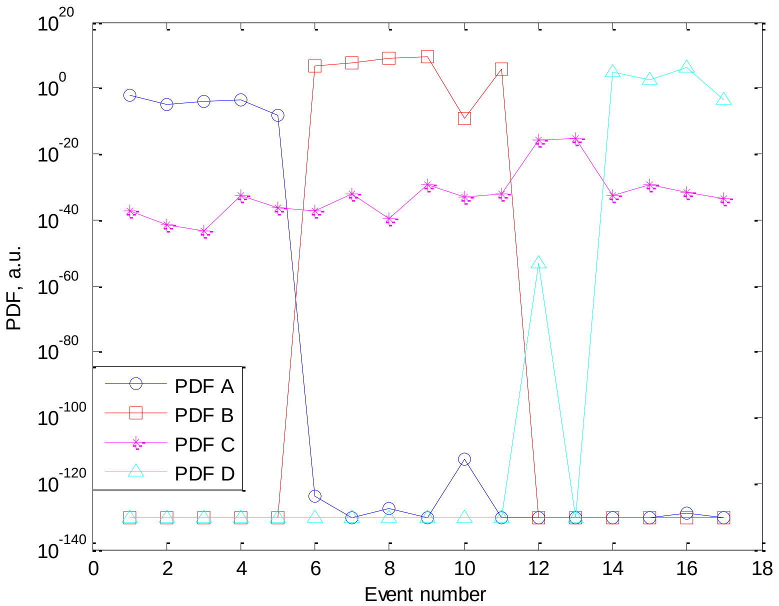


Figure 12. PDF-s corresponding to our algorithm that is based on a multivariate statistical technique, the classification is based on the maximum PDF value for each event. The actual event sequence is: A (1-5), B (6-11), C (12-13) and D (14-17). The wrong classification for event 12 is marked with an ellipse.

Figure 13 shows the results of the combined method; the combined method also detects 100% of appliances in this series.

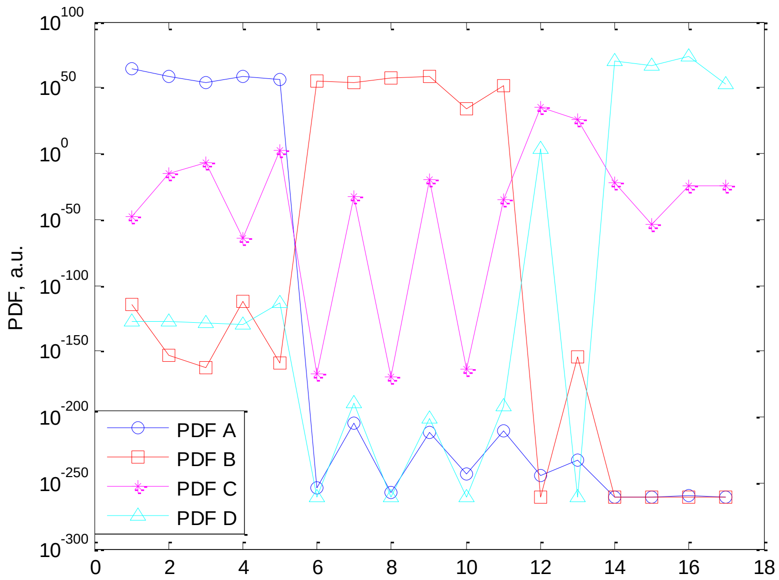


Figure 13. PDF-s corresponding to the combination of two algorithms, the classification is based on the maximum PDF value for each event. The actual event sequence is: A (1-5), B (6-11), C (12-13) and D (14-17). The wrong classification for event 12 is marked with an ellipse.

Finally, we used our iMEL-C system to follow the four appliances during an eight-hour period. During this time, we turned on and off the appliances and manually recorded the corresponding events. In total, there were 31 such events. After that, we applied our algorithms to reconstruct the appliance states. Figures 14 and 15 show the results.

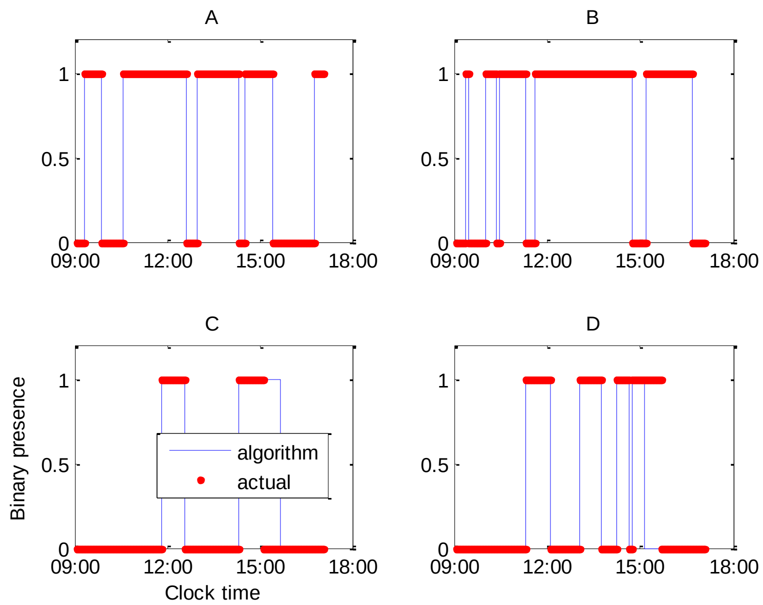


Figure 14. Disaggregation results for our harmonics-based algorithm. Appliances: CFL lamp (A), CRT TV (B), incandescent special lamp Luminaire (C) and fan (D).

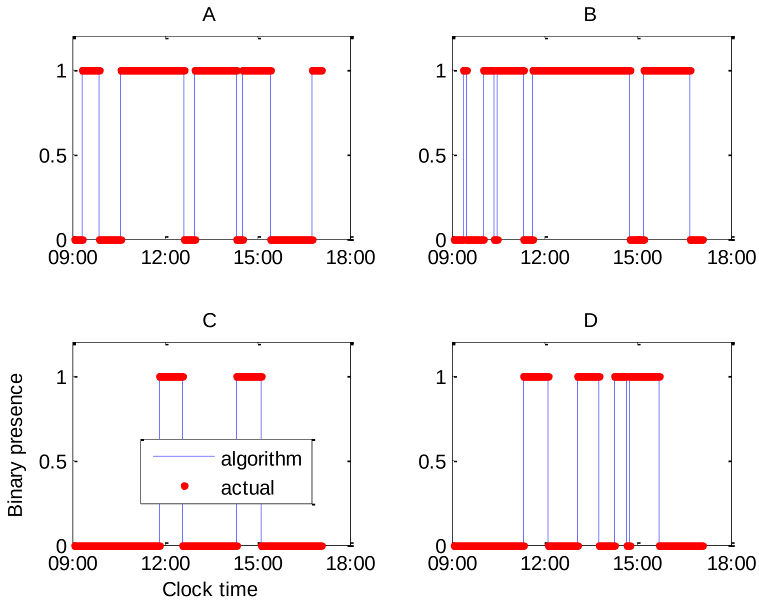


Figure 15. Disaggregation results for our multivariate-statistics algorithm and for the combined algorithm. Appliances: CFL lamp (A), CRT TV (B), incandescent special lamp Luminaire (C) and fan (D).

Figure 14 suggests that one transition was classified wrongly, so that the accuracy of the harmonics-based algorithm can be estimated as 30/31 = 96.8%. Both the algorithm based on a multivariate statistical technique and the combined algorithm provide a perfect reconstruction (100% accuracy), as can be seen in Figure 15.

5. Conclusions and Future Work

We have presented two different NIALM methods suitable for two different sensor types. The method suitable for a low-frequency sensor outperforms the existent NIALM method for the on/off appliances and, potentially, for the multistate appliances. Its accuracy for the simulated data is about 97%. The method suitable for a high-frequency sensor attains 100% disaggregation accuracy for the limited experimental data we collected.

In future work, we will further develop the first method and apply it to real data. We are currently monitoring two households using TEDs, and we will use the obtained data to benchmark our VAST algorithm. Since this algorithm involves transition probabilities, it can be combined with our second method that uses probabilistic pattern recognition. In this way, we can improve the accuracy and robustness of our approach.

Further, we expect to extend our approach to the permanent and variable-load appliances. The NIALM solution methods proposed for these appliances [8] can be implemented and combined with our main approach.

Acknowledgement

This work was supported in part by the U.S. Department of Energy under a subcontract with Lawrence Berkley National Laboratory number 6926442. We are grateful to Rich Brown of LBNL for helpful discussions.

References

[1] Darby S. *The effectiveness of feedback on Energy Consumption. A review for DEFRA of the literature on metering, billing and direct displays*, Environmental Change Institute University of Oxford, 2006.

[2] Gölz, S., Götz, K., Deffner, J. *Smart Metering – a means to promote sustainable energy consumption? Socio-technical research and development on feedback systems*, Proc. of the EEDAL-2009, p. 3.

[3] Likkanen, L. A., *Extreme-user approach and the design of energy feedback systems.* Proc. of the EEDAL-2009, p. 23.

[4] Van Elburg, H. *Encouraging public support for smart metering via appealing and enabling in-home energy feedback devices*. Proc. of the EEDAL-2009, p. 57.

[5] Pedersen P.E. *Impartial quality tests of compact fluorescent lamps*. Proc. of Right Light 4 (Copenhagen, Denmark, 19-21 Nov. 1997). ISBN 87-87071-73-8. Can be ordered from Borg&Co AB Services.

[6] Ehrhardt-Martinez, K., K.A. Donnelly, and J.A. Laitner, *Advanced Metering Initiatives and Residential Feedback Programs: a Meta-Review for Household Electricity-Saving Opportunities*, Report E105, ACEEE 2010.

[7] Lipoff, S., *Home Automation – the Unrealized Promise*, IEEE Consumer Electronics Society Newsletter, pp. 13-14, Fall 2010

[8] Zeifman, M., Roth, K., *Nonintrusive Appliance Load Monitoring: Review And Outlook*, Proceedings of IEEE Conference on Consumer Electronics, p. 243, 2011.

[9] Hart, G. W., *Nonintrusive Appliance Load Monitoring*, Proceedings of the IEEE, Vol. 80, pp. 1870-1891, 1992.

[10] www.theenergydetective.com

[11] www.google.com/powermeter

[12] Drenker, S., *Nonintrusive Monitoring of Electric Loads*, IEEE Computer Applications in Power, p. 47, 1999.

[13] Albicki, A. . and A. Cole, *Algorithm for Non-Intrusive Identification of Residential Appliances*, Circuits and Systems, Proceedings of the IEEE International Symposium on, Vol. III, pp. 338-341, 1998.

[14] Baranski, M., J. Voss, *Non-Intrusive Appliance Load Monitoring Based on an Optical Sensor*, EEE Power Tech Conference, Bologna, 2003.

[15] Matthews, H. L., *Automatically Disaggregating the Total Electrical Load in Residential Buildings: a Profile of the Required Solution* Intelligent Computing in Engineering - ICE08, 2008.

[16] Zeifman, M., Roth, K., *Viterbi Algorithm with Sparse Transitions (VAST) for Nonintrusive Load Monitoring*, Proceedings of IEEE Symposium on Computational Intelligence, 2011 (in press).

Energy Monitoring, Comfort and Control from Your Armchair

Martin O'Hara[1], Robert Blackwell[2] and Tony Taylor[3]

Danfoss Randall Limited[1], Simply Digital Consulting[2], Utility Partnership Limited[3]

Abstract:

SMaRT Action (Smart Metering and Real Time Action) is a UK project part funded by the Technology Strategy Board (TSB) to demonstrate how integrating energy monitoring and controls for various devices around the home into one easy and simple to use interface, can effect change in the way that users interact with their energy use and comfort control. The key innovation of SMaRT Action is providing real time energy information and advice via an on screen display to any existing television (TV). Providing the information in this way is expected to drive user engagement though making information easier to access in a less intrusive manner than a dedicated in-home display (IHD) unit that is currently the proposed solution for "smart" energy display. In addition the project will provide the user with the ability to immediately take action via their TV remote control, such as turning off lighting or appliances, or reducing the room temperature set-point. SMaRT Action; providing energy monitoring, comfort and control without having to leave your armchair.

Background

In June 2010 the UK Technology Strategy Board (TSB) requested competition tenders for projects to examine how after the UK roll-out of Smart Meters, these meters can integrate into homes to enable the transition to a low carbon economy and accelerate the speed of market innovation. Due to the UK General Election in May 2010 the initial notice had been postponed and consequently the competition projects had to be started in October 2010 and completed by March 2011, hence a very tight timescale for such technology projects in which to deliver any useful data.

A consortium formed by Danfoss Randall Ltd (DRL), Simply Digital Consulting (SDC) and Utility Partnership Ltd (UPL) won a bid for approximately £230k (€260) matched funding; the consortium members have to contribute an equal amount to the project, hence the total project fund was double this amount. The funding was to procure, install and monitor domestic energy systems based around the existing TV as the information display for energy meters and other energy consuming devices in the home, and to determine how the user interacted given this data provision; SMaRT Action – Smart Metering and Real Time Action.

Introduction to SMaRT Action

The initial bid was based around utilizing commercially available products that could be obtained from the market at the start of the project in October 2010, partly due to the very tight 6-month project cycle, but also to prove what is achievable today. The primary focus was to be the ease of installation of the systems, collecting, collating and displaying the data to determine the level of home owner engagement when the information display is the TV.

Part of the concept is to minimize disruption to the home, hence install without any infrastructure change, primarily to ensure that the system was a suitable retrofit solution for post-smart meter homes but also to minimize timescale and installation costs. It was important that the total cost per home was not prohibitive and where possible could be scaled and expanded as required. There is also an additional TSB requirement that the outcome is exploitable post-project, hence the consortium had to also ensure that a larger scale roll-out is possible, that other projects could be operated over the same or similar systems and that expansion, updating and reuse of the installed system is all possible.

System Components

Although a single in-home network is preferable, the consortium recognize that it is highly unlikely that in the long term a single network may be mandated for Smart Meters or in-home control networks. However, for expediency the consortia had to ensure that inter-operability issues would not significantly impact a project on such a tight timescale, hence only products conforming to the Z-Wave wireless communication standard were considered for the SMaRT Action system.

Components were selected from available marketed devices (figure 1); no new physical component would be created for this project due to the very tight timescale. The devices would be going into peoples homes, with the intention of being left there post-project, and they had to be proven functional products (not prototypes) and where possible the user operation had to be as familiar as possible to similar "non-smart" equivalents to ensure users did not have a significant learning curve to become familiar and engage with the products and system.

Figure 1: SMaRT Action System Components; 1. Energy Speedo Display, 2. 3View Set-Top-Box, 3. Room Thermostat, 4. Light Switch, 5. Appliance Plug, 6. Electricity Meter, 7. Gas Meter Logger.

It is also worth noting that no two applications in the home are supplied by any single product supplier, even the gas and electricity metering solutions are from different suppliers. The consortium felt it was important not to lock the SMaRT Action project or system into any single supplier and it is hopefully open enough to be configured using similar products from other suppliers.

Details on the specific models and suppliers is provided in Appendix A at the end of this paper.

Energy Speedo

The information collected from the meters is displayed in a similar fashion to a car instrument cluster or speedometer, hence became known as the "Energy Speedo". UPL developed this initially as a web service and it can be accessed via a PC or other display terminal if necessary. The data routing and transport can be over internet or other media if required outside of the home (e.g. GSM/GPRS).

In-Home TV Display

Although the TV will be the in-home display, it can be relatively safely assumed almost all homes already have a TV, hence the mechanism for placing the information onto the TV is through a set-top-box (STB). This is supplied by 3View Ltd, a company with whom SDC have worked since their inception. As well as enabling the Z-Wave information to be displayed, the STB features a free-to-view high definition (HD) digital TV receiver and hard-disk drive (HDD) personal video recorder (PVR).

The STB was also seen by the consortium as a way to easily get the “buy-in” from the home occupiers to allow access to their properties for the installation and monitoring periods.

Heating Circuit

Space and water heating accounts for the largest percentage of domestic energy consumption, greater than most people’s energy consumption due to transport. This is an area where interaction could potentially have the greatest impact on creating a low carbon economy, however, has not been a major focus for Smart Metering as the Utilities appear to have primarily focused on electricity whereas in the UK heating is mainly supplied by the gas network with approximately 95% of the housing stock having an independent gas boiler for the home.

Danfoss are supplying a wireless thermostatic control and boiler interlock that is suitable for use in the majority of UK domestic heating circuits that supplies water based heat to radiators. The electronic room control is deliberately kept as simple to operate as a mechanical type, although the set-point and measured temperature are displayed on the product in a small LCD.

Lighting Circuit

There will be 2 lighting circuits per installation. While the consortium recognized that this is not ideal for every size of property, for planning and installation purposes (and budgeting) this limitation was set to enable some of the home lighting circuits to be monitored by the SMaRT Action system.

Appliances

Each installation will be provided with 2 appliance sockets that can be user fitted between the standard UK 3-pin plug socket and an appliance. These sockets have manual over-ride and can supply up to 3kW of AC load, although they are not capable of measuring the load on the plug (other types may be available that have load measurement capability after this project).

Energy Meters

It was also recognized that although the focus for the TSB competition is aimed at the post-Smart Meter roll-out, there are very few Smart Meters currently installed and finding and using these homes would be too limiting for this project, hence the SMaRT Action project would also have to include the installation of Smart Meters themselves within its scope. Consequently a Z-Wave billing certified electricity meter (Horstmann S123R) and gas meter logging unit (Technolog Zmart Link) were installed in each property.

System Configuration and Installation

The proposed typical system configuration is shown in figure 2; comprising the energy meters, STB, heating circuit, 2x lighting circuits and 2x appliance plugs.

The data internal to the home is transported on the Z-Wave in-home wireless network. The meter data is transported back to the utility provider (via UPL) via an internet connection from the STB; the STB is internet enabled to primarily allow narrowband video access (e.g. BBC iPlayer, YouTube etc.).

System Installation Restrictions

Using the TV as the primary display device does limit some homes from being included, particularly homes where cable or satellite services was the primary provision of TV content (e.g. Sky, Virgin media etc.) since any messages appearing via the 3View STB would not be visible if this was not the primary content source for the TV. Similarly to maintain a measure on both gas and electricity, only gas meters with R5 connection could utilize the gas logger chosen early in the project scoping phase and hence could be retrofitted without the needs to swap out the gas utility meter.

During the initial scoping phase with many of the HA’s, it also became apparent that replacing the electricity billing meter could cause an unacceptable delay to the installation. Additionally, there is currently no available Smart Meter for electricity that allows pre-payment options, not an uncommon feature in private tenanted UK properties. To avoid having to exclude the pre-payment residents or creating unacceptable delays with utility meter swap-out, it was decided to install the electricity meters as "sub-meters", i.e. install after the billing meter without removing the existing meter installation.

The above limitations were necessary to both manage the installation scope and to try to maintain as low an impact as possible on existing infrastructure in the home (including the TV infrastructure).

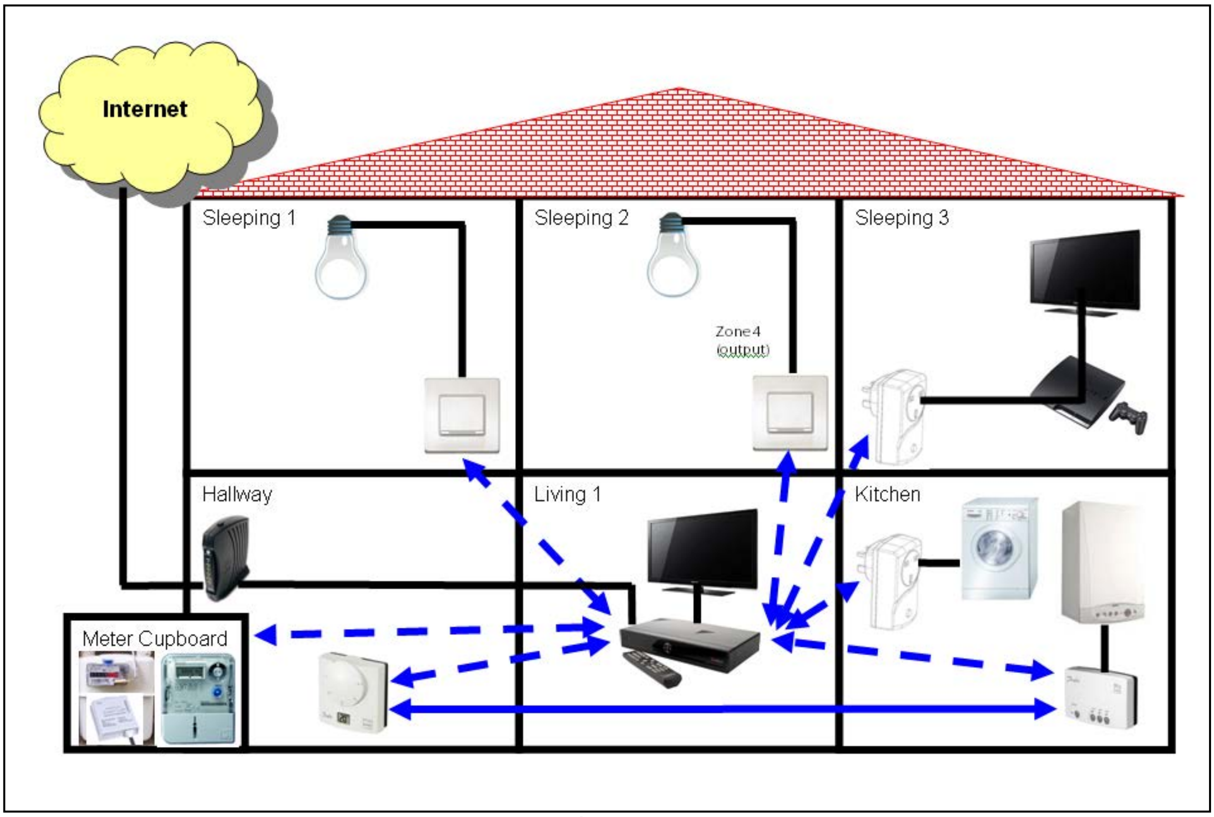


Figure 2: Typical system installation (black connections represent hardwired, blue connections represent wireless).

Installation Service

Installation in the candidate homes will be conducted by the preferred installer organizations of the HA's, this is to minimize the required management of the installations for the consortium and also to provide a local single point of reference and known provider of post-install service provision should there be any need to replace, change or remove the system. This is being conducted on a standard commercial basis between the consortium and the installers.

Energy Meters

As mentioned above, to minimize disruption and maintain the project timescales, electricity metering will be installed as a sub-meter rather than the primary billing meter. This has an additional benefit for those homes where the metering is relatively remove from the home (e.g. apartment blocks with centralized metering) where there could be additional issues with the RF network at large (>30m) distances.

The gas meter logger is a simple R5 connected unit with a 10-year battery life. It is expected that during the life of this product all standard gas utility meters will be replaced by true Smart Meter equivalent, but for this project a "quick-fix" plug-in providing the gas-pulse information only is being utilized. This also has the benefit of not requiring any interference with the gas network supply or pipe work itself, this significantly reduced the installation cost.

Set-Top-Box

The STB is developed as a user installable item, however, for the trial these will also be installed by the electrical installer of the rest of the system.

Heating Circuit

The boiler interlock fits onto a standard British Gas (BG) wall-plate, common in many UK homes, hence those homes that already utilize this fixture will require a simple remove-and-replace operation. Where this wall plate is not available, a wall plate is provided with the receiving unit that can be located close to the heating appliance (usually a gas fired boiler), with the battery operated thermostat placed wherever the current thermostatic control is positioned.

Lighting Circuits

The lighting circuits fit into standard UK electrical fixing boxes, hence the existing mechanical switches need to be removed and replaced with the supplied parts. The lighting utilizes a common neutral connection, this may limit the number of properties that this can be installed in as this is a more modern method of wiring, hence there may be some older properties that prove unsuitable to have all the components fitted. If this proved the case these properties will have all other components installed and the lighting circuits returned to the consortium.

Appliance Plugs

The appliance plugs will be left with the home occupier to choose where they want to use these items. It may be that they choose not to use these, which in itself could be a useful piece of data.

Project Candidate Homes

The scope of the original bid had been for up to 250 homes being installed in the project timeframe, however, due to a series of initial delays with both funding and then product delivery, this was downscaled to 150 homes. The access to target properties was decided, pre-project, to be via Housing Associations (HA's) and Local Government Associations (LGA's) where these looked after the housing stock. It was felt that this approach had the greatest chance of achieving the number of target installations that with the scope we had set-out to achieve only these organizations could deliver the candidates and installations within the project timescale, and this has proven to be the case.

At the time of writing this draft paper, installations have yet to be started, however, at this time there are over 250 potential candidates have been identified, although this is still expected to be reduced to a final installation number of 150 homes once the candidates are further criteria selected. The current installation forecast is to start in mid-February, with completion by the end of the first week in March 2011.

Geographic Spread

While a geographically diverse portfolio of installations is desirable, in the project time scale, many HA's that were interested were unable to commit to the project. Despite this limitation and relatively small number of installations, across the South-central belt of England and South Wales the consortium managed to achieve a good spread of locations ensuring that rural, semi-rural and urban populations will be included in the trials.

A total of 6 HA's and one LGA were participants in the project; Pembroke, United Welsh, Coastal Housing, Milton Keynes Council, Clapham Park Homes, Flagship Housing and Wherry Housing (the later having 2 dispersed locations for the installation candidates, see figure 3).

Figure 3: Geographic spread of candidate installations

Housing Type Diversity

Again despite not being in a position to force housing stock diversity on the project applications, the SMaRT Action Project has achieved a relatively diverse range of house stock type and resident type. Not all data is currently available at the time of writing this draft, but a number of apartments, single story houses (Bungalows) and multi-story houses are already signed up for the project.

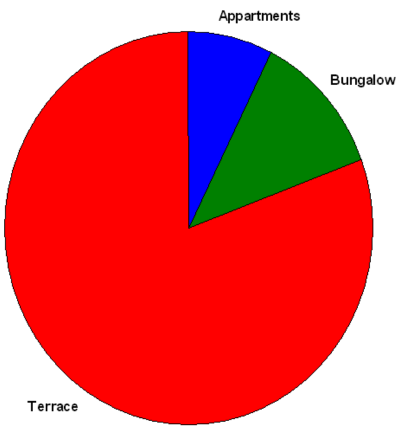


Figure 4: Housing type diversity (only one HA so far with this specific data)

Home ownership in the UK is relatively high in comparison to many European countries, however, as the project was targeting HA's for the source of stock we did not expect to achieve significant insight into privately owned homes. However, due to the nature of one of the sites, we did obtain access to approximately 30 private homes and hence comparisons between the energy use in private and rented accommodations may be possible.

Broadband Access

One issue that was of concern was the access to broadband services in HA and LGA homes which typically can be lower income and have limited access to digital services. However, this has proved not to be the case and only 29% of the candidates that applied did not have broad band access. It is recognized however that this may be masking the truth in that some potential applications may have decided not to apply because they did not have such a broad band service, hence although here the broadband access looks relatively high at 65%, this is a small sample and should not be used to forecast this issue wider than this specific project (figure 5).

House Park Suitability

The full impact of SMaRT Action user engagement relies on the STB being the main source of TV provision; hence display items can always be available "on the screen" as overlays from the STB. Consequently those whose primary TV provision is via satellite or cable, it is unlikely they would switch to the terrestrial provision via the STB (figure 7). The suitability of the house park investigated indicates that in social housing, due to broadband/internet availability and satellite/cable TV provision, only 32% of the houses approached (457 homes in total), were suitable for installation. Some of these homes include those with internet connection, but no broadband, hence could not fully utilize some of the STB features; approximately 150 homes were selected for installation.

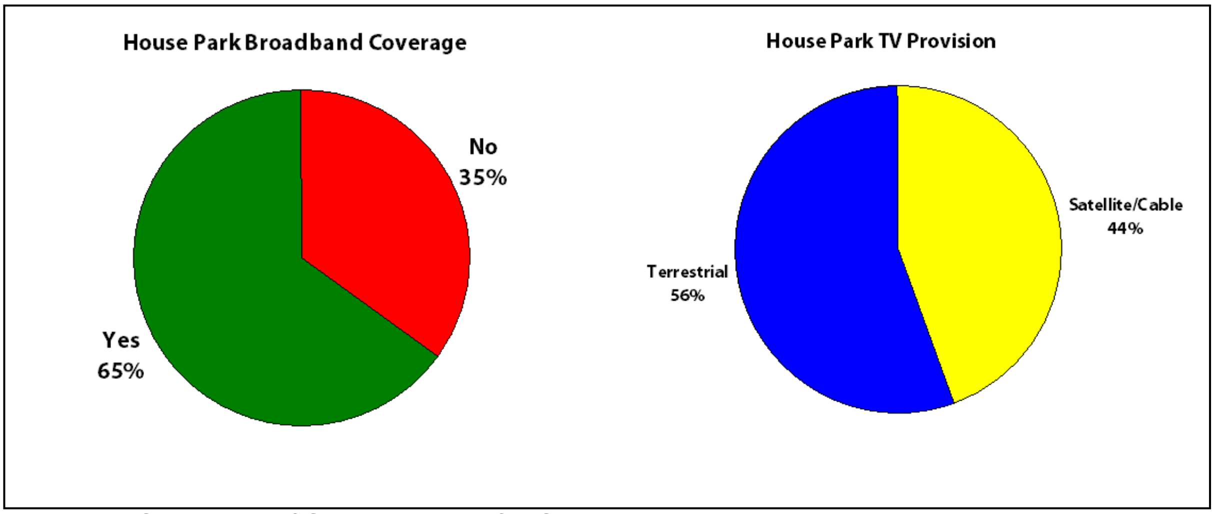


Figure 5: Suitability of Social Houses for SMaRT Action Installation.

There was some variation across the geography examined, but off too small a difference to be statistically significant within the scope of this project.

In the UK it should perhaps also be noted that the country is presently switching over from analogue to digital terrestrial TV, the digital switch-over is due form nationwide completion in 2012. Consequently many homes are looking for STB type solutions for this, plus new HD services only available via the digital service. In these instances the SMaRT Action system addresses this social change as well as the Smart Energy project.

The Cost of Smart

The project was not specifically looking at the cost of implementing a Smart Home, but as a consequence of the scale of installations and system that is being installed (from off-the-shelf products), a very clear indication of what this cost of "Smarting" a home has been gained. It is also a cost for retrofit, another area that is often overlooked when considering the Smart Home; typically new build, state of the art computer controlled systems are considered, here we have more typical UK domestic properties with near-standard products (lights and thermostats).

Component Costs

Although we were purchasing a relatively large number compared to a single home owner might, the quantities and costs would not be unrealistic for a typical domestic installation company such as those that were used for this project. As a consequence, for a large scale roll-out of SMaRT Action systems, maybe as a pre-defined kit, these costs are probably not untypical of what the installer may pay for the components (figure 6).

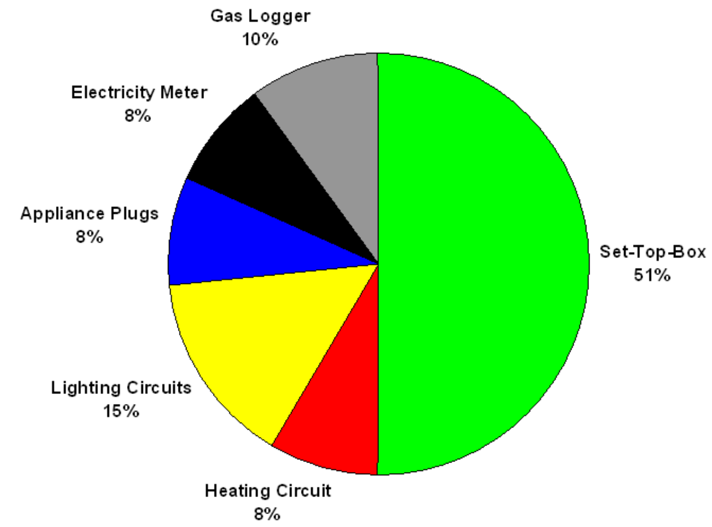


Figure 6: System component cost breakdown (cost share in percentages)

The result is a total system component cost of approximately £600 (€675), however, this includes the metering here. If SMaRT Action is considered for a post-Smart Meter roll-out, the total cost for these components, per home, reduces to under £500 (€560).

Installation Costs

The costs here may be slightly less than a single home resident would pay since we have been able to achieve some scale and most of the properties have been local to the installer and in relatively close geographic areas per HA. Additionally the installers had no administration to conduct with the ordering and supply of parts, this was handled within the SMaRT Action consortium, so again the costs incurred are likely to be lower in this project instance than a single resident might pay. Despite these vagaries, the total cost of installation, including a short term service contract, should be in the region of £400 (€450) per home.

It also needs remembering that this installation cost includes electricity sub-meter installation and installation of the gas meter logger. If this project is rolled out post the UK Smart Meter installation programme, some of these costs can be removed from here.

Running Costs

These are not included in the project, but it should be borne in mind that for full functionality of the STB a broadband connection is required. All other running costs are as per standard domestic home, there are no additional running costs associated with a SMaRT Action Smart Home for the resident.

System Cost per Home

The funding model for the project was based on a £1000 per home cost and that is what the project has achieved, almost to the penny! This does include the metering costs, which are shown separately for their material part and the small installation cost reduction that may be achieved is not included (figure 7). This total system cost is also for the relatively fixed SMaRT Action configuration, it is recognized that homes are not so prescribed, some will want more lighting circuits, some no lighting but a different heating circuit (maybe a programmable thermostat), others will want stored hot-water included in the heating etc. As a consequence the costs provided here can only be used as a rough guide, but even so, it is clear that many homes can be converted to a Smart Home of some description for less than £1000 (€1125).

The STB, as noted above, is just over 50% of the total component costs, if these are purchased already as part of the digital switch-over in the UK, again on-cost per home will be further significantly reduced.

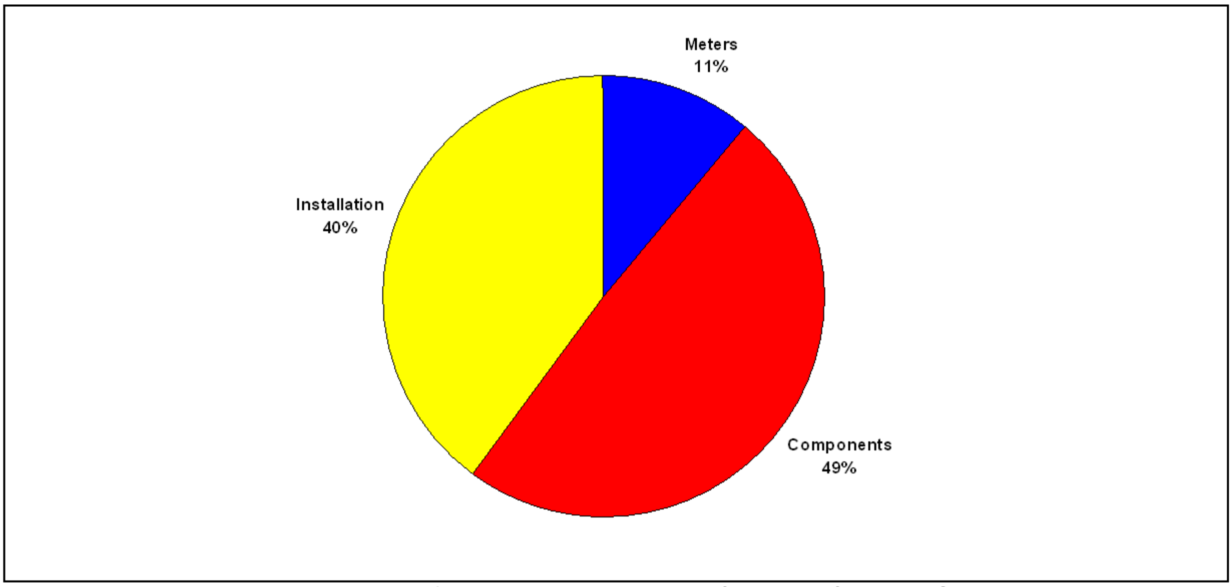


Figure 7: Where the money goes? The cost breakdown for retro-fitting a Smart Home.

Results

The primary display channel for the system is via the STB, however, unknown at the start of this project, the Z-Wave hardware within this product had never been enabled. This was not discovered until November 2010 when test systems were being built. The problem was believed to be programming at the STB contract manufacturer, and ultimately this has proven to be the case, but partly due to a business split within the SDC and 3View organization at the end of 2010, the issue was not resolved within the project time-frame. As a consequence, to avoid spending the TSB funding on a system that was known not to function, the installations were never commissioned.

As a consequence actual test data is not available, but the method of obtaining results can be presented to allow the reader to gauge what might be possible once the system is finally running.

User Engagement

The STB has a hard disk drive (HDD) and the engagement from display to product, even though not through the STB, can be monitored over the Z-Wave network (e.g. if there is a flag for high energy use, the operation of the thermostat will be recorded over the Z-Wave network and could be logged on the STB HDD). This type of interaction can be time-stamped for relating engagement to display information, similarly if the display is deliberately brought up and then enacted upon, this can be recorded. All user engagement information can then be downloaded through the STB internet connection for off-line analysis.

User Surveys

User surveys have already been conducted via other trials through the STB. It was envisaged that further user surveys would be conducted as part of the on-going exploitation of the SMaRT Action project. These would be essentially on-line surveys, but conducted via the STB and its remote control to enable quick response and easy engagement again from the resident.

Paper surveys, such as those already conducted forming the basis of the suitability study, could also be performed by the HA's, either as part of this project or separately.

Pro-Active SMaRT Action

An area that was to be considered post project was the use of suggested messages on energy consumption, to not only re-enforce user engagement, but to try and drive behaviour change. For example it was always considered a long term objective to be able to give people comparative energy data, such as "you are using 20kW per week, the average for this area is 18kW per week." Further development of this could be to make active suggestions, such as "Your thermostat is set 1°C above the mean for this area, try reducing this to save you energy."

Exploitation

Despite the lack of installations, due to the interest shown by residents and HA's, even when notified the project would not make installation, there is a high probability that once the STB Z-Wave function is resolved, a limited number of these installations will commissions during 2011 via other funding methods (there is still the possibility that the unspent TSB funding may be released to complete the project).

Going forward from SMaRT Action itself, there are further potential areas that the system and the products used can be exploited to assist in both the transition to a low carbon economy and to break down other social and economic schemes. Already mentioned above the relatively high level of broadband access into social housing means that as a simple to use and integral item, the STB could assist with "Digital Inclusion" programmes, this is an area in particular some of the HA's in this trial were keen to explore, where local services and information could be provided over the STB internet link to the TV.

Similarly other active engagement processes could be enabled, such as rewarding economic energy users maybe with local HA benefit advantages, such as reduced cost access to leisure facilities.

Another area that is already being developed on the back of the SMaRT action project is use in Telecare, where the Z-Wave network activity can be monitored to determine house-hold activity and in-case of inactivity raise alarms or auto-distress calls to local wardens.

Conclusions

Having no current installations there are few immediate conclusions that can be drawn on user engagement, but then in the project time frame little was expected to be known. However, some conclusions can be drawn from the project, mostly on cost and the suitability of such a system for UK homes.

It is possible to retro-fit the SMaRT Action system in a domestic home for under £1000 and further savings on this cost would easily be possible should the Smart Meter technology already be deployed. The system is also scalable, it is relatively easy and comparatively low cost to add additional lighting or heating circuits, it is also expandable, more circuits can be added after the initial installation and the network extended, being a single radio technology this is reasonably straight-forward using the STB as a primary controller.

Another issue highlighted is the limitation of using a STB as the only display device, clearly in the social housing sector a relatively large proportion of the population already have provision via cable or satellite, hence an alternative solution using these service providers would also be required to ensure 100% UK domestic compatibility. Most of these service providers also use dedicated STB type products, adding the Z-Wave controller code and network access via a USB type dongle could be possible in most, although the service provider's interest has yet to be tested.

Lastly there is without doubt a clear appetite in the UK for some such retro-fit smart energy solution as proposed by SMaRT Action, this is clear not only from the enthusiasm shown by those involved above, but in their willingness to pursue the project even after the funding for installation had to be stopped. In today's economic climate, local authority spending is severely limited, hence willingness to spend some on such a project clearly shows both commitment to the principle and faith in the potential of the system to deliver across a range of energy and related social programmes.

Acknowledgements

Michael Snaith of Unseen Networks was engaged with much of the work to develop the HA contacts, particularly outside of South Wales, and was instrumental in the project being able to gain the number and quality of participants within the project time frame. We would also like to acknowledge the positive reception of the concept and assistance with the South Wales HA's from Dr. John Littlewood of UWICS, and his involvement in potential post-project exploitation for other building research programmes.

The suppliers of the components were also especially helpful in enabling the parts to be available within the time-frame. It is also a credit to all the HA's and LGA that participated that they too were able to react within this time and provided the data on house park suitability that has enabled the project to provide some useful data. Additionally all the residents that were willing to have these installations deserve recognition for their participation.

Appendix A: Component Details

Set-Top-Box; 3View Ltd, Model: 3viewHDMk1, www.3view.com

Heating Circuit; Danfoss Randall Ltd, Models: RET-B-Z and RXZ1 supplied as a pack (087Nxxxxx), www.danfoss-randall.co.uk

Lighting Circuit; MK Electric (Honeywell), Astral Lighting series, Models: switch LSM11U C and cover-plate LSF11U WHI, www.mkelectric.com

Appliance Circuit; Everspring, Model: AN148, www.everspring.com

Electricity Meter; Horstmann, Model: S123R, www.horstmann.co.uk

Gas Data Logger, Technolog, Model: Zmart Link, http://www.technolog.com/

References

[1] van Dam, S.S., Bakker, C.A., van Hal, J.D.M 2010 "Home Energy Monitors: Impact Over the Medium-Term," Building Research & Information, Vol. 38, No. 5, p. 458-469.

[2] Michelle Shipworth, "Thermostat settings in English houses: No evidence of change between 1984 and 2007", Building and Environment, Volume 46, Issue 3, March 2011, Pages 635-642

[3] A.D. Peacock, D.P. Jenkins, D. Kane, "Investigating the potential of overheating in UK dwellings as a consequence of extant climate change", Energy Policy, Volume 38, Issue 7, July 2010, Pages 3277-3288

[4] P.J. Boait, R.M. Rylatt, "A method for fully automatic operation of domestic heating", Energy and Buildings, Volume 42, Issue 1, January 2010, Pages 11-16

[5} S. Firth, K. Lomas, A. Wright, R. Wall, "Identifying trends in the use of domestic appliances from household electricity consumption measurements", Energy and Buildings, Volume 40, Issue 5, 2008, Pages 926-936

[6] Adam Faiers, Matt Cook, Charles Neame, "Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use", Energy Policy, Volume 35, Issue 8, August 2007, Pages 4381-4390

[7] J. Peter Clinch, John D. Healy, Cost-benefit analysis of domestic energy efficiency, Energy Policy, Volume 29, Issue 2, January 2001, Pages 113-124

Tomorrow's households: How do consumers react to a smart-home environment?

Alexandra-Gwyn PAETZ[1], Elisabeth DÜTSCHKE[2], Wolf FICHTNER[1], Martin WIETSCHEL[2]

1) Karlsruhe Institute of Technology (KIT), Chair of Energy Economics
2) Fraunhofer Institute for Systems und Innovation Research ISI

Abstract

The Karlsruhe Institute of Technology (KIT) has set up an innovatively furnished smart home that integrates different energy-related technologies. The kitchen is equipped with smart household appliances that can react to external (price) signals. An energy management system (EMS) can optimize the power generation – e. g. through photovoltaic-modules – and consumption in the most efficient way, e. g. cost-efficiently.

For this study, 29 consumers divided into four focus groups have experienced this environment and discussed implications for their everyday behaviour. The topics that were also demonstrated in practice included variable tariffs, smart metering, smart appliances and home automation.

In general, group reactions towards the smart home environment were positive. Consumers saw many advantages for them and emphasized the expectation that the equipment shown in combination with variable tariffs will offer the chance to save money. For a minority of participants, the possibility to lessen their individual environmental impact was perceived as the main motivation for changing their homes. The majority, however, saw environmental effects as a positive side-effect. It was regarded as difficult to give up high levels of flexibility and adapt everyday routines according to current electricity prices. Smart appliances and smart meters were therefore seen as necessary preconditions by most participants. Concerns regarding data privacy protection played a major role in one of the groups.

Currently test-inhabitants are living in the smart home for several weeks to experience this environment on a daily basis.

Introduction

The energy system is facing new challenges due to the increasing supply of decentralised and renewable energy as well as the lack of possibilities to store electric energy in the grid. Load management measures, such as variable tariff models can play a key role as a solution to these challenges. On a European level this issue has been enforced with the directive 2006/32/EC, which has been transposed into national law in Germany and prescribes that energy suppliers have to offer some kind of tariff that motivates private consumers to save energy and / or shift electricity loads from on- to off-peak periods[1]. Furthermore, new buildings in Germany have to be supplied with smart meters[2] since January 2010. Variable tariffs and smart meters are often seen in combination with other smart home devices in order to allow consumers transparency for realizing energy savings and load shifting potentials.

Current estimations on the present and future investment in smart metering in the European Union present values as high as 51 Billion EUR [1]. Electricity companies have started to offer variable

[1] The Law (§ 40 EnWG) defines that these are variable tariffs.

[2] The Law (§ 21b EnWG) describes meters that allow the user to identify the current level of energy consumption and the real period of energy use.

electricity tariffs, and smart household appliances are increasingly offered on the market accompanied by field tests for smart metering devices.

However, hardly any consumer has seen and experienced the combination of all of these components that are supposed to contribute to a more energy efficient and sustainable everyday life as full solutions are not offered on the market up to now. Smart metering devices are singularly available; however, many utilities are still working on the development of accompanying products such as internet platforms that allow for monitoring household electricity demand. Smart appliances are offered as well, however the majority of consumers still lack the additional technical installations to make use of the ‘smart’ additions. Thus, up to now, it is not clear how consumers perceive the new possibilities that come with these products and technologies[3].

In this paper, we therefore analyze consumer perceptions and evaluations of the full range of energy-related innovations that are to be combined within a smart home environment: variable tariffs, smart metering, smart appliances and home automation. For this analysis we use a unique environment, a fully furnished and operating smart home building developed and erected in 2010 by the Karlsruhe Institute of Technology (KIT). Four focus groups with an overall participant number of 29 experienced this environment and discussed their perceptions within a moderated group discussion. In the following, we will first give a more detailed description of the smart home environment; next we briefly summarize the state of knowledge from the literature and outline our research questions. The following section presents the focus group study and the paper closes with a short summary and a discussion of the results, pointing out limitations of the current study as well as conclusions.

The Smart Home Environment

The Karlsruhe Institute of Technology (KIT) has set up a fully furnished 60 m² smart home that consists of two bedrooms, a living room, a bathroom and a kitchen (cp. Figure 1). The kitchen is equipped with smart appliances[4] that are able to receive communication signals and provide extensive information on their operating state, such as the remaining time of the dishwasher's current program. Furthermore photovoltaic-modules (PV) and a bock heat and power plant (micro CHP) can generate electrical power at the smart home.

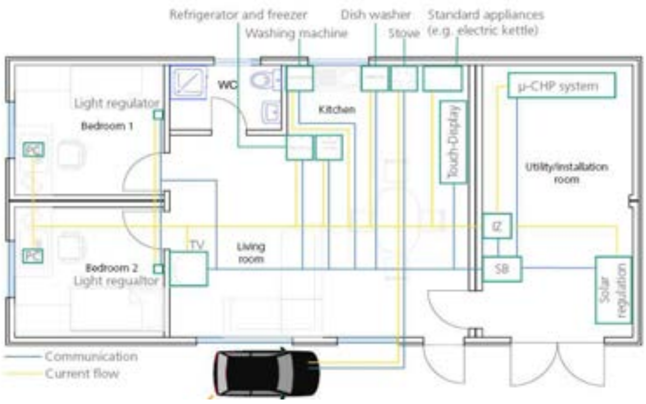


Figure 1: Sketch of the smart home layout on KIT’s campus

---

[3] Throughout this text we will use the word “technology” when referring to all four future products under study – variable tariffs, smart metering, smart appliances and home automation – although not all of them are new technological developments.

[4] The following appliances in the kitchen are „smart“: freezer, dishwasher, tumble dryer, washing machine. All other appliances in the house are controllable via the power switches.

All data about electric power generation and consumption in the house is monitored and collected in a central controller box that works as an energy management system (EMS). The EMS can schedule the operation time of each appliance according to external (e.g. price) signals and maximize the consumption of the internally generated power. It is possible to specify preferences in the EMS, such as the time by which the dishwasher should be ready, in order to provide flexibility and convenience to the smart home residents.

All rooms are therefore equipped with energy management panels (EMP) realized as touch screen displays, which allow for interaction between the resident and the EMS. The overall state of the smart home, such as the level of electricity consumption and generation, can be visualized on each EMP and the residents can enter their individual preferences. The generic software of the EMPs can also be used on smartphones, so that the residents are able to analyse their electricity consumption easily at any time and place.

Even though a couple of smart homes have been presented in the research landscape, no house shown so far unifies the concepts of electric power generation, consumption and the interaction with real residents.

State of Research

Literature Outline

Although smart homes and the connected technologies and products are becoming available on the market hardly any research exists yet that includes first-hand consumer experiences. However, some literature has been published on smart metering, variable tariffs as well as the usage of displays and other features in order to support monitoring of electricity demand and electricity saving efforts. On top of this, some market research surveys and some qualitative studies have addressed issues of smart appliances and home automation. This literature is reviewed on an exemplary basis in this section.

Using smart meters, real-time feedback or variable tariffs to increase awareness of energy use by private consumers is not new (cp. [2], who published a study in 1983 in which consumers were confronted with varying time-of-day price ratios). However, with the political developments referred to in the introduction, the technological development and in the wake of climate change research interest has currently risen again.

Darby summarizes research that proves that enhancing the frequency of feedback on consumption (e.g. through more regular bills) enables and motivates at least some consumers to reduce energy demand [3]. Worldwide energy companies have introduced variable tariffs, often in combination with smart meter trials, in order to learn about these effects: Results indicate that reductions of energy demand are possible in a range between five to 25 % [3, 4]. However, stability over time is not clear yet. Moreover, other studies paint a less optimistic picture with regard to savings: Allen and Janda conducted a study which included a real-time energy feedback using a digital electricity monitor which was tried out by ten households for a period of several months. While households increased awareness the effects on electricity consumption were marginal to non-existent [5]. Results from an ACEEE report show that the overall energy savings also depend on the focus of the research program: programs focused on peak load shifting save considerably less energy than programs focused on promoting conservation and efficiency at all times [6].

For Germany, an extensive study by forsa, conducted on behalf of the Verbraucherzentrale Bundesverband e.V., the leading consumer advice association in Germany, analyzed perceptions and evaluations of smart metering [7]. An initial focus group study showed that the consumers' level of knowledge on smart metering is low. For example, the English term smart meter – which is often used by German energy experts – was completely unknown to all focus group participants. In a follow-up survey using a sample of more than 1,000 participants only three per cent knew the real meaning of the term. The German term "intelligent" or "new" meter was slightly more familiar in both studies, still a vast majority had not heard of it. After a short explanation about the concept of smart metering, first reactions by participants of the focus group and the survey were positive. Participants in both studies saw the advantage of having the chance to reduce spendings on electricity and to have a higher level of cost-control, but doubts about the real potential for saving electricity and costs were also strong and concerns about necessary investments and misuse of data were dominant. The possibility that home automation could be a future feature in addition to the smart meter was also welcomed hoping for more convenient household management, however, fears were expressed with regard to necessary time and effort.

Home automation was also discussed with participants of a study by IBM [8]. In this study, consumers stated willingness to reschedule household activities – such as turning on the dish-washer – to off-peak periods; however, consumers objected to adjustments to cooking or using entertainment equipment. In-depth interviews as part of the Intelliekon-project showed different results [9]: Consumers claimed that nearly all of their household activities took place within a narrow time frame and could not be rescheduled. This perception was especially strong for families and single persons.

In sum, current literature points out that consumers usually show positive reactions if confronted with smart homes and the related technologies. On a general level, knowledge and awareness seems to be limited. Main driver for adoption are potential cost benefits, however, consumers also anticipate several disadvantages. Findings on actual behaviour are mixed; there seems to be some realistic potential for energy saving effects; however, the validity of these studies is not clear as also contrary findings have been published. This result has to be seen in relation with study results on potential behavioural adaptations which have also presented mixed findings.

Research Questions

Literature findings do not allow for formulating precise hypotheses on consumer perceptions. Thus, this study takes an exploratory approach. The focus is on consumers' first reactions to the full range of technologies demonstrated within the smart home environment. What is the general reaction to the full future scenario presented? How are the different elements, i.e. variable tariffs, smart metering, smart appliances and home automation, perceived? How realistic is their integration into a household's everyday life in the near future? What barriers need to be overcome? Can these technologies lead to a more efficient use of electricity from a customer's point of view? And how will marketable products have to be designed to be successful?

Focus Group Study

Methods

In order to answer the research questions outlined above we chose an exploratory design based on focus groups. Focus groups are a method to elicit and explore opinions and are therefore especially useful if individuals are confronted with innovative products. On the one hand focus groups allow for a close interaction with the researcher and the technology; on the other hand participants have the opportunity to ask questions and also to stimulate each other in bringing up associations and perceptions to discuss them as a group. Focus groups thereby offer the chance for the researcher to develop a deep understanding of why people feel the way they do (cp. [10]). Due to group dynamics, issues are often raised that probably would not have come up in individual interviews.

Obviously, based on focus groups it is not possible to provide conclusions that are representative for a certain population or to make precise quantitative predictions about the development of a certain product. The outcomes of a focus group study strongly depend on the participants – thus selection of participants is an important step. Additionally, each group develops specific dynamics – so it is usually advisable to conduct more than one focus group.

For our study, 29 individuals attended one of four focus groups which all followed the same design and lasted between 2.5 and three hours. This included a pre-post-questionnaire and a sequence of short presentations or scenario demonstrations given by the moderator, followed by extensive group discussions which were supported and if necessary guided by a guideline of specific questions.

The size of each group was between six and nine individuals. All groups included women and men, however, overall men were in the majority (18 out of 29). Participants were relatively young on average as the first two groups consisted of students while the other two were dominated by 'average' residents from the Karlsruhe area (range 21 to 61 years, 21 individuals younger than 30 years). Recruiting student groups was motivated by the following reasons: First, students were regarded as one of the main target groups for actually living in a smart home environment in the future as they usually do not already have fully equipped homes and the technologies will probably be available on the market when they start investing in equipment. Second, as the KIT is a university with a strong technological focus, it was expected that students would be relatively open to the technologies presented. Third, it was assumed that students have not developed firm habits for everyday life with regard to managing the household and will therefore be more flexible about choosing e.g. a variable tariff. Thus, students are an interesting, however special group. Therefore, two additional groups were conducted that mainly consisted of individuals beyond 25 years, who were already established with regard to household and working life. For these groups, recruitment aimed at creating heterogeneous groups with regard to professions, age, and social background (e.g. level of education).

Participants were recruited using various ways including mailing lists of universities, newspaper ads, and flyer distribution. Participants received a fee after the group discussion (30 EUR). In sum, 19 out of the 29 participants were university students. Of the remaining ten, seven were employed or self-employed in various fields including cosmetics, healthcare and energy industry. Three were either unemployed or retired. Four of the participants indicated that they were the only member of their household, nine lived together with partners or family, and 16 – all of them students – lived in a shared apartment. The household size varied between one and 15 individuals. Four participants currently shared their household with children.

Groups took place in the living room including the open kitchen of the smart home and were moderated by the first author of this paper while the second author assisted. When participants arrived they received a questionnaire including questions about socio-demographical background, assessment of attitudes towards environment / economy / technology adoption and about energy-saving activities. The group discussion then started with collecting associations about electricity and electricity use and then went to electricity tariffs with short explanations about standard tariffs, time-of-use tariffs (one with two different time periods and another one with three different time periods that changed every 24 hours) and load-dynamic tariffs (with two load-zones). After discussing tariffs, smart meters were introduced and their attributes demonstrated by showing the actual smart meter as well as additional applications (e.g. graphs of electricity consumption of the current day on a screen) and then discussed by participants. Next, smart appliances from the smart home kitchen were shown and as an example it was demonstrated, how the dishwasher automatically started its washing programme based on electricity price information. The last feature presented and discussed with the groups was the full automation of the smart home. The groups closed with a final round asking for an individual, final evaluation of the elements presented. At the end the post-questionnaire was distributed asking for ratings on the technologies demonstrated in the smart home as well as price preferences.

In the pre-questionnaire participants indicated, that from their perspective, preserving the environment is the most important challenge of our times (86 %; other possible answers were economic development, health care, unemployment and crime). The four groups did not significantly differ on this rating. Another question asked about their attitude towards technological innovation: 76 % indicated that they appreciate trying out a new technology, 24 % stated that they preferred to wait until others have gained experience with an innovation. The third category, sticking to proved and tested technology, was not chosen at all. Thus, also compared to other samples of our research, participants claimed relatively high levels of technological affinity.

The group discussion was recorded and transcribed literally afterwards. The transcripts were then coded, based on a preliminary code manual that was developed according to the focus group guideline. This manual was further refined throughout coding two of the groups and repeatedly discussed between the first two authors of this paper. Then an agreement on the final code structure was found and all groups were re-coded according to it. Final codes – amongst others – refer to the technology currently discussed, behavioural intentions and attitudes towards the technology, motives expressed as well as specific suggestions in relation to the technology. In order to secure coherent understanding and usage of the code manual the first author coded all four groups while the second author checked the codes of two groups; however, only minor disagreement came up in this process.

In the following section the results of all focus groups will be presented and illustrated by participants' quotes. All quotes have been translated into English retaining the gist of the original German statement. Every participant was given a number during the anonymisation process. The digits after each quote refer therefore to the participant and the focus group he or she took part, such as P1-1 for participant number one that took part in the first focus group.

Study Results

In general, group reactions towards the smart home environment were positive. Consumers saw a lot of advantages for their own households in the usage of the equipment demonstrated. Many benefits were perceived for all technologies, the most important being monetary savings. The higher the saving and the shorter the payback time of the investment for smart home equipment, the better was the evaluation from a customer's point of view. In line with this, variable tariff models were the most popular choice for the near future, as no significant investment in hardware is needed. However, it was regarded as difficult to give up high levels of flexibility and structure everyday life in order to react to different electricity price levels as in the case of variable tariffs. So the main barrier for adopting a new technology is the cognitive effort for changing behavioural patterns. In the following section the evaluation of each technology is presented in detail.

Variable Tariffs

Electricity tariffs that vary in price per kWh are attractive to a majority of participants (22 out of 29 participants), of which all would consider to choose a variable tariff in the near future with a strong preference for time-of-use tariffs. There are two main motivations for this positive evaluation: the possibility of saving money and electricity. While the monetary incentive is valid for all participants with the exception of one, the benefit of saving electricity is mainly seen as a positive side effect. This goes along with another environmental benefit that was viewed to be good but not essential in the personal decision making process: the possibility of integrating more renewable energy into the grid, as consumption follows different price levels which again depend on the availability of renewable energy – meaning for example having lower price levels when enough energy is produced by wind turbines and offering higher prices when there's no wind.

- “Obviously I’m thinking also about the environment, but personally my biggest motivation is savings.” (P 22-3)

For a few participants, however, environmental benefits play a key role in the decision for an electricity tariff. They are very much in favour of integrating more renewables into the grid and already use an eco-friendly tariff. Their willingness to consider a variable tariff depends mainly on the improvement of their ecological footprint. Interestingly enough, these environmentally friendly participants perceive the calculation of variable price levels by the energy supplier with distrust and need the assurance that the calculation is correct.

- “Even though I believe that generating electricity from wind is a great concept, I’m not sure whether I can trust those large power companies that they actually supply green energy.” (P 24-4)

When thinking about daily patterns doubts arise about how much of the actual consumption can be shifted in the household. Nobody doubts that it is possible to shift a few predictable activities, such as using the dish-washer or the washing machine, as long as it remains convenient. That means in the case of time-of-use tariffs that the low-priced time periods should not start too late in the evening in order to avoid conflicts with other household members or neighbours. This concern is especially expressed by the student participants, who more frequently lived in multi-storey buildings.

- “I live in a shared apartment on the 2^{nd} floor and have neighbours above and below. I can’t regularly start the washing machine at 11 pm. Thus a night-time tariff would be useless to me.” (P 9-1)

Furthermore tariffs with low level of variability are preferred: Tariffs with a set schedule of price periods were rated better than tariffs with dynamically changing rates (i.e. price levels, time periods or load zones). Answers from the post-questionnaire show that a majority of 17 participants (61 %) would prefer a fixed price per kWh with a validity of at least a month or longer. Five indicated agreement with changing price rates within a day or even shorter periods, six favoured weekly changes.

The reason is univocal: there’s a strong feeling that trying to adapt to a variable tariff would mean giving up high levels of flexibility and being occupied with checking price levels and planning the consumption for the next day. With exception of one participant nobody believes that the coordination with other household members would work on the long run. Thus the perceived cognitive effort required is the main barrier for all participants when it comes to behavioural change.

- “I definitely don’t want to think about electricity prices every minute and castigate myself according to a household plan.” (P21-3)

As no monetary savings can be achieved without adapting consumption patterns to the variable tariff, one point of discussion is, whether monetary savings can be a higher incentive than the convenience from “consumption-as-usual”. The Price Sensitivity Meter Analysis from the post-questionnaire shows that the point of indifference is at savings of 80 EUR per year, i.e. lower savings are not perceived as motivating to change behavioural patterns.

Another much discussed issue is how to offer and design variable tariffs in order to increase their usability and attractiveness. Many ideas include the information needs around variable tariffs, especially load-dynamic tariffs. Therefore it is suggested on the one hand to get more information, to visualize it, e.g. through a phone application, and to get feedback, especially on the environmental impact of tariffs. On the other hand participants think of supplementary equipment such as automated computer systems that recognize the price information and then either automatically turn on the household appliances or suggest to the user how to use them in the most efficient way.

- “Some computer unit that can recognize the price level and tell the dish-washer to start during a cheap time slot. That would be great.” (P13-2)

Smart Metering

As described in the section above, consumers want more transparency and feedback, especially visualizing the impact of their consumption pattern on costs and the environment. All groups are positively impressed by the smart meter that shows the load curve of the smart home in real-time over the internet or on touch screen displays.

- “This is exactly the curve I’m looking for! Really impressive, because now I can see my consumption, and electricity is no longer invisible.” (P5-1)

The first reactions are very positive and the participants are looking for strategies how to get most information out of the smart meter. Apart from two participants that already have detailed knowledge about their household consumption, the others anticipate to analyse the load at home and to discuss that with the other household members.

- “I’d start turning on and off every appliance in order to see its impact on the load curve. Maybe it would be also interesting to borrow some home devices of my neighbour and see who is more efficient. This nourishes my playing instinct.” (P17-3)

Even though a few strongly believe that they would start to use the household appliances more efficiently because of the constant feedback they would get by the displays, there is a broad consensus that the continuity of looking at the load curve decreases in time.

- “After a while I would know more or less how much I consume, and if I don’t change anything substantially such as exchanging a less efficient appliance, there would be no need for looking at the load curve regularly.” (P26-4)

A third of the participants say that they would not consider the acquisition of a smart meter. There are three reasons for it:

1. Especially for the student participants the smart meter is not rated as innovative and helpful enough for their information needs and daily routines: “To me the smart meter is not transparent enough, because it just shows me my total load curve. This piece of information on its own is nearly worthless if it is not used for further technical purposes.” (P7-1)
2. Two participants have concerns due to data privacy issues and therefore reject the technology in principle: “No, that’s unthinkable to me. That’s sensitive information. The utility could easily see whether I’m at home or on holidays.“ (P24-5)
3. The feeling of not being able or not having the possibility to do more towards living more energy efficiently was another reason to refuse a smart meter to one participant: “I’m hardly at home, I only use the washing machine once a week. What do I need the smart meter for? I will never save enough electricity to payback the meter.” (P17-3)

The price of smart meters is generally an important issue for those who consider buying one. The acceptable price for non-students is realistic within a range between 40 and 120 EUR. However, the expected payback period is rated relatively short with just one year. Many even feel that the utility should provide smart meters to everybody for free.

- “The smart meter doesn’t only offer advantages to us. The utility has most benefits, because they can buy electricity according to our consumption data and save money in the supply. So, why don’t they just exchange the meters and we both can benefit from it?” (P20-3)

By the end of the discussion a majority would consider the acquisition of smart meters, however, most would only consider it in combination with a variable tariff in order to have a higher incentive to save money and be more motivated to change daily routines.

Smart Appliances

Household appliances that are able to communicate and react to external signals are perceived as the inevitable future by all participants, especially when it comes to variable tariffs. On the one hand smart appliances offer higher levels of flexibility when using such a tariff, and on the other hand they only have an environmental impact if they are used in combination with them, as their price levels also depend on the availability of electricity from renewable resources in the grid.

- “I can save time, if I don’t have to care about the price levels and tariffs myself and coordinate all the consumption. That would be great.” (P22-4)

White goods are seen as ideal to be exchanged for a smart version, as its consumption is high and its optimized use could lead to substantial monetary savings. While the use of consumer appliances, such as cooking, entertainment and lighting are also discretionary, these are considered more necessary and consumers are less likely to change their use based on a variable tariff.

- “Everything that I can shift is OK, such as the freezer. I guess the TV is a good example for the contrary. I watch the news at eight o’clock and I wouldn’t want it to turn off automatically due to a higher electricity price. So I don’t think that smart technology makes sense for anything else than white goods.” (P2-1)

A few participants question the wisdom of time-of-use tariffs and doubt their ecological effect, as the smart appliances have to be turned on in order to be able to receive signals and start, for example, a certain washing program.

- “I don’t believe that it’s very efficient. Let’s say that I load the washing machine and it has to stay in stand-by for hours because the next low-price level is not active before. We have been taught to avoid leaving appliances on stand-by.” (P5-1)

Even though the concept of smart appliances is appealing to all participants, nobody considers exchanging their household appliances in the near future, because there are only very few products on the market and therefore their prices (examples were provided by moderator) are too high – especially too high, when considering a possible payback period. In any case there is consensus among the participants – regardless of their technological orientation – that the acquisition of smart appliances would only be considered if the current appliances stopped working properly.

- “Wait with the smart dish-washer until the current one breaks down. It doesn’t make sense to throw away a well-working dish-washer and buy a smart one instead that costs twice the price. How could I ever save that much electricity afterwards?” (P17-3)

Home Automation

Besides the option of manually turning on household appliances and that of automatically switching on smart appliances through a home automation system (as demonstrated in the previous section), a third option was discussed: handing over the automation system of the home to a third party by remote control, which can be a utility or a demand side manager. Even though only one participant saw advantages for him in the remote control option, this option was discussed the most and raised many questions. The main concern expressed by everybody – regardless of age – was the data privacy issue. For both automation options, the participants demand the possibility of opting out and using the appliances manually, for example turning on the washing machine manually when needed, regardless of the current price level.

- “The remote-control option is no alternative for psychological reasons, because it’s strange to feel somehow observed.” (P8-2)

The home automation system was appealing to half of the group, because most information of the EMS, such as detailed load of each appliance in use, stays within control of the house and relatively few information is sent out to the utility via smart meters, e. g. the total load curve. The main incentive to choose smart appliances and implement a home automation system is a higher degree of convenience when it comes to variable tariffs.

Regarding other household members neither home automation nor remote of control systems are rated as positively as the other technologies discussed, because the effort coordinating all household members is expected to be higher. Another barrier for integrated automation systems at home is the lack of standards and a general technical complexity behind these systems. So even though some see advantages for themselves in the automation solutions, nobody is concretely planning to retrofit their homes.

Discussion

Summary and discussion of results

In this study 29 participants in four focus groups discussed energy-related technologies that aim for a more energy-efficient everyday life. A quasi-experimental design in a smart home on KIT’s campus was used to demonstrate four technical innovations: variable tariffs, smart metering, smart appliances, and home automation. First reactions towards the technologies demonstrated were positive and participants had the perception that the usage of the equipment could be advantageous for them. The most important benefit was monetary savings. Positive evaluations increased with the magnitude of assumed financial benefits and with shorter payback periods for the smart home equipment. Variable tariff models were most popular from the technologies presented, as they do not afford significant initial investment in hardware. However, to change daily routines and / or decrease the level of individual flexibility in order to adapt to different electricity price levels as in the case of variable tariffs was evaluated negatively. Thus, the main barrier for adopting this new technology is the cognitive effort for changing behavioural patterns. Therefore most participants wish for supplementary solutions that facilitate the usage of variable tariffs, such as smart appliances and home automation systems. However these two technical innovations are hardly considered as an option for the acquisition in the near future. In contrast, obtaining a smart meter is worthwhile to the majority of participants, when more variable tariffs are offered on the market.

After completion of the focus group interviews two test-inhabitants moved into the smart home for a period of three weeks. They experienced the smart home environment with the technologies demonstrated to the focus groups on a day to day basis. This living phase was accompanied by an online-blog and a follow-up in-depth interview. A preliminary evaluation shows that – contrary to the focus group perception – living with smart home technologies did not require additional cognitive effort in the temporary inhabitant’s point of experience. However, the inhabitants clearly confirm that – from their perspective – the only incentive to adapt consumption habits will be a monetary benefit.

This goes along with the focus group results and another experience shared by one participant during the discussions who had already installed a smart meter at his home:

- “We always wash our clothes Wednesday mornings and sometimes on the weekend if the machine is fully loaded. Why should we change that? If you want to achieve a change, offer me money.” (P25-4)

The motives for adopting or refusing smart home technologies abstracted from the results can be broken down to five key drivers: price, convenience, ecology, transparency and technical equipment. These drivers are itemised in Table 1 below.

Table 1: Main motives for adopting or refusing smart home technologies

Main incentives for adoption	Main barriers for refusal
• Monetary savings	• Cognitive effort / confirmed habits
• Lower ecological footprint	• High expenses
• Increased convenience	• Ecological sense
• Higher transparency	• Data privacy protection
• Technological orientation	• Technical complexity

The innovative attractiveness of smart home technologies is not the central key driver – regardless the consumer’s technical orientation – for adopting these energy-related technologies. Thus other benefits have to be offered that go along with the consumers’ desire to get easy and simple advice on how to save on electricity expenses. Transparency about consumption and costs can satisfy the information needs on the short run and therefore be a good starting point in offering attractive solutions. As in the case of smart meters our study shows that supplementary applications have to be integrated in order to satisfy consumer needs in the long run.

Limitations

As all empirical work this study is subject to several limitations. Certainly, generalizability of the findings is limited. The sample recruited for this study is not representative for any kind of population – younger adults with a high level of education are overrepresented. All participants rated themselves relatively high with regard to interest in technological innovations; moreover, participants were recruited after they had joined up voluntarily, i.e. they were not recruited using some kind of random approach. Thus, individuals not interested in this kind of technological development as well as those holding strong reservations were probably not present in the groups and their views are therefore not covered in our study. However, when recruiting participants for the focus groups we tried to engage individuals who are likely to be among the early majority that will be open for embracing smart home technologies. Additionally, the scope of the study is limited geographically as only German participants from a narrow area in Western Germany (around Karlsruhe) took part. Investigating cultural and structural effects is therefore necessary. Moreover, while the KIT-smart home offered the unique chance of illustrating the possibilities offered by such an environment this is also a limitation as smart home environments that are designed in a different way may also elicit different reactions.

Conclusions

Our study sheds more light on the motives for adopting or refusing smart home technologies. It turns out that besides the very central incentive of saving money, lowering the environmental impact, maintaining high levels of flexibility, increasing transparency about electricity consumption and costs as well as an enthusiasm for new technologies are likely to play a role. In order to further deepen our understanding of these topics several test-inhabitants are moving into the smart home on KIT’s campus and experience the smart home environment with its energy-related technologies on a daily basis. Even though the first living phase has been completed, more living phases are required to further analyse how new technologies can change consumers' behaviour to a more efficient use of electricity.

Additionally it might also be useful to survey individuals who have already installed various energy-related technologies in their homes. In this context the detailed analysis of the various field tests with smart meters throughout Europe will deliver interesting results in the near future.

As variable tariffs were valued as the most attractive solution in this study further analysis of consumer's preferences regarding different types of variable tariffs as well as their real effect on the consumption in households appears to be worthwhile.

Based on the results of this study we recommend for politics and industry to design integrated offers in order to support the market entrance for energy-related smart home technologies. Market offers have to satisfy consumer needs for convenience, transparency and usability which are currently not met by a singular technology. The combination of smart meters – for their transparency – with variable tariffs – for their cost-saving potential – and smart appliances – for their usability – has been the most preferred one in this study.

- "All I wish for is a simple structured variable tariff maybe with a smart meter. As soon as the tariff gets complex I need smart appliances, otherwise I wouldn't be able to shift my consumption according to the price levels. And it has to be user-friendly without an engineering approach." (P29-4)

Acknowledgements

This research was made possible as a part of the project MeRegioMobil, which is funded by the German Federal Ministry of Economics and Technology (Grant 01ME09005).

References

[1] Faruqui, A., Harris, D., and Hledik, R.: *Unlocking the €52 Billion Savings from Smart Meters in the EU*. Energy Policy. 2010 (10), pp 6222-6231.

[2] Heberlein, K. and Warriner, G.K.: *The influence of price and attitude on shifting residential electricity consumption from on- to off-peak periods*. Journal of economic psychology. 1983 (4), pp 107-130.

[3] Darby, S.: *Smart metering: what potential for householder engagement?* Building research & Information. 2010 38 (5), pp 442-457.

[4] Sustainability First and Engage Consulting Limited: *International Smart Meter Trial Selected Case Studies Smart Tariffs and Customer Stimuli*. (2008, May. http://www.sustainabilityfirst.org.uk/publications.htm (28/01/11).

[5] Allen, D. and Janda, K.: *The effect of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study.* ACEEE Summer Study on Energy Efficiency in Buildings. ACEEE Summer Study on Energy Efficiency in Buildings. Ed.: American Council for an Energy-Efficient Economy, Washington: 2006.

[6] Erhardt-Martinez, K., Donelly, K.A., and Laitner, J.A.: *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities*. ACEEE Report Number E105, June 2010.

[7] forsa: *Erfolgsfaktoren von Smart Metering aus Verbrauchersicht*. Bericht. 2010. Berlin: forsa.

[8] IBM Global Business Services and Zentrum für Evaluation und Methoden der Universität Bonn: *Preis, Verbrauch und Umwelt versus Komfort – der mündige Energieverbraucher.*

Verbrauchsverhalten und neue Möglichkeiten zur Kundenbindung und Kundengewinnung für Energieversorger. 2007. http://www-05.ibm.com/de/pressroom/downloads/energie-studie.pdf (28/01/11).

[9] Birzle-Harder, B. and Deffner, J., Götz, K.: *Lust am Sparen oder totale Kontrolle? Akzeptanz von Stromverbrauchs-Feedback.* 2008. Can be ordered from http://www.shop.isoe.de/.

[10] Bryman, A.: *Social Research Methods.* New York. Oxford University Press. 2001. ISBN 01-992-0295-8.

Measuring the Usability of Appliance Controls

Alan Meier*, Cecilia Aragon*, Daniel Perry**, Therese Peffer, Marco Pritoni****, Jessica Granderson****

**** Lawrence Berkeley National Laboratory, ** University of California, Berkeley, *** California Institute for Energy and Environment, **** University of California, Davis***

Abstract

A "smart" device will remain efficient only as long as the settings and other parameters allow it to be. Thus, the degree of usability is becoming an element of energy efficiency similar to other physical characteristics. We developed and tested a procedure to quantify the usability of thermostats. The procedure assumes that usability can be represented by a user's ability to accomplish a set of tasks. Thirty one subjects were tested in their ability to accomplish six essential tasks on programmable thermostats. The tests revealed a wide variation in the subjects' ability to accomplish the same task on different thermostats. Thus it was possible to discern thermostats that were more effective than others. We created a metric based on data that are easy to collect and unambiguous that appears to reflect the usability of a task. Metrics from different tasks can be added and an overall usability "score" calculated. This approach, as well as the metric, can be applied to other devices where poor usability may impede energy-saving behaviour.

Background

The controls of energy-using products are becoming increasingly sophisticated in order to provide both more features and increased energy efficiency. Most products covered by minimum energy performance standards (MEPS) now incorporate a microprocessor, a display, user input devices (e.g., keypads), sensors and other means of information input and output. The microprocessor takes these inputs, makes decisions, and determines the operating mode. Table 1 shown as Table 2 lists some modes for refrigerators, televisions, and heat pumps. Each mode results in a different level of energy consumption.

Table 1. Potential modes in three appliances.

Device	Modes (partial list)
Refrigerators	Compressor on (variable) Defrost on Fan on (variable) Ice making on Anti-sweat heater on External display (on/off/sleep) Data send/receive Microprocessor on
Televisions	Display on Brightness (variable) Sound level Timer Motion sensor control Resolution (variable)

	Automatic programming guide Fan (variable) Standby functions Screen saver
Heat pumps	Compressor on (variable) Fan (variable) Defrost heater on Crankcase heater on Display on Remote control active Timer active Off, but processor on

The enhanced controls can also lead to user confusion. A naïve user may inadvertently select settings resulting in higher energy consumption than necessary because the device's user interface employs:

- unfamiliar or inconsistent terms or symbols
- awkward procedures to change settings
- opaque procedures to make changes
- ergonomically difficult features

These problems appear in many types of appliances and energy-using equipment. The problem of inconsistent terms and symbols has been described in office equipment by Nordman [1]. However, similar cases are common in appliances, consumer electronics, and lighting controls, such as:

- Inconsistent symbols: in thermostats controlling heat pumps, the status light indicating operation of (high-cost) resistance heating use may be red or green (depending on model). Manufacturers also use at least three different terms for it.
- Awkward procedures: a thermostat requires over 10 keystrokes to lower temperature prior to leaving the building
- Opaque procedures: motion sensor is activated by rapidly flicking the light switch 4 times to enable or disable it.

When confronted with these situations, users—even those with the greenest intentions--will often select settings that are more convenient over energy saving. Many of these problems are related to the usability of the device, where usability is defined by ISO as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"[2].

Different approaches can be taken to improve usability and minimize user confusion. One approach is to harmonize the critical terms and symbols associated with the interface. In this way, users are more likely to be familiar with basic controls even when they confront an unfamiliar device. Nordman [3] describes how certain symbols were standardized for power controls in office equipment .

One obstacle to improving usability is the absence of recognized procedures to measure and quantify usability. Manufacturers have no way to compare prototype interfaces, consumer organizations have no means to rate interfaces, and governments have no metric for establishing minimum levels of usability. We describe below a methodology to quantify the usability of programmable thermostats and results of laboratory tests of five thermostats. This methodology appears suitable for measuring usability in other devices relying on complex controls.

Evaluating usability of products is commonplace; however, most evaluations address usability of one-off items, such as controls in airline cockpits or websites. The typical procedure is to compare one version against an improved version. To our knowledge, this is the first quantitative usability test developed for mass-produced products.

Measuring the Usability of Thermostats

In North American homes, a single thermostat typically controls the heating and cooling equipment. In the last fifteen years, digital, programmable, thermostats have been introduced. These thermostats allow the occupants to set a schedule for heating and cooling and save energy compared to constant temperatures. A schedule involving nighttime temperature setbacks (or set-ups in the cooling season) has been shown to reduce heating use 15% compared to constant temperature settings [4]. About 40% of U.S. homes now have programmable thermostats. Almost all new single-family homes have programmable thermostats and, in some regions, building codes require all new homes to be equipped with them.

Nevertheless, several evaluations in different parts of the United States found that homes with programmable thermostats actually used *more* energy than those operated with manual thermostats [5]. This is no surprise because a broad array of studies have found that the advanced features of programmable thermostats—and especially the programming capabilities—are rarely used and often bypassed by the occupants [6]. A major explanation for failure to exploit the programmable thermostats is the difficulty in setting and changing them; in other words, these thermostats suffer from poor usability.

A Usability Score Based on Tasks

Some thermostats are easier to operate than others. But how can the superiority of one interface be measured? Ideally, the test method should resemble an energy test procedure, that is, be clearly defined, and have repeatable, quantifiable, results. These measurements of usability could then be used to establish a “usability score” which would allow manufacturers, consumers, and regulatory agencies to rank thermostats and establish minimum criteria for usability. We therefore investigated the feasibility of quantifying usability of thermostats. The procedure is based on controlled interactions between people and thermostats.

The measurement method involves two steps:

1. Define representative tasks to be accomplished with the thermostat;
2. Measure people’s ability to perform those tasks under controlled conditions using defined metrics.

The first step in measuring usability is defining the most common tasks associated with the thermostat. A “task” might be as simple as ascertaining the status of the thermostat; for example, “Identify the temperature the thermostat is set to reach”. Alternatively, a task might involve changing the operation, such as, “Program the temperature to be 22°C on Tuesday evenings at 7 PM.” Assembling tasks involves studying the operating manuals and carefully observing and interviewing users. It is also necessary to consider if the user is expected to interact with the thermostat as a total novice (such as when one enters a hotel room), daily, or somewhere in between. From a long list of tasks, we selected six that typified the range of tasks a typical user would need to understand in order to effectively operate the programmable thermostat. The list was further constrained by requiring that the tasks could be accomplished with most common programmable thermostats. The six tasks eventually selected were:

Task 1: Turn the thermostat from “off” to “heat.”

Task 2: Set the correct time.

Task 3: Identify the temperature the device is set to reach.

Task 4: Identify the temperature that the thermostat is set to reach for Thursday at 9:00 PM.

Task 5: Put the thermostat in “hold” or “vacation” to keep the same temperature while gone.

Task 6: Program a schedule and temperature preferences for Monday through Friday.

The above tasks are clearly defined and can be easily explained to test subjects. Successful operation of a programmable thermostat requires proficiency in other tasks but these are representative; in other words, if users can perform these tasks, then they can use the most important features of the thermostat. The same approach could be applied to other sorts of controls, such as for lights or heat pump water heaters.

We sought to observe in detail and record different aspects of usability with which we might offer indicators of usability. The following aspects were collected for each subject during each test:

- success or failure in accomplishing the task;
- elapsed time to accomplish the task;
- number of times buttons were pushed (or other actions);
- sequence of actions;
- hesitations; and
- verbal comments.

We recorded the sessions with a video camera; this way we were able to convert the data collected on a video record and determine the aspects listed above.

Our initial goal was to determine the viability of the task-based methodology and the identification of the best metric. Did the test procedure generate a significant range in the metrics? Did the test procedure applied to different thermostats generate a significant range in a metric? Finally, was one metric superior to others?

Details of Experiment

Five programmable thermostats were selected for testing. Three were primarily controlled through a touchscreen and one was a web-based interface. The tests were conducted at a usability laboratory. The laboratory set-up was very simple (see Figure 1). A video camera recorded each test in the vicinity around the thermostat (so the subject's face was not captured). The camera captured images similar to that shown in Figure 2. Thirty-one participants were recruited (22 male, 9 female), with ages ranging from 18 – 65. The subjects had many different occupations and varying levels of previous experience with programmable thermostats. Each subject was tested on two thermostats. Each test consisted of six tasks. Altogether 62 tests were performed, consisting of 372 tasks.

Figure 1. Laboratory set-up for measuring the usability of a thermostat.

Figure 2. Still image from a video of a person performing Task 1.

Results: Metrics of Usability

A wide range of usability was observed. Figure 3 shows the pooled results when the subjects were asked to perform Task 1 ("turn the thermostat from off to heat") on the five thermostats. Each subject performed Task 1 on two different thermostats. The metric was elapsed time to complete the task.

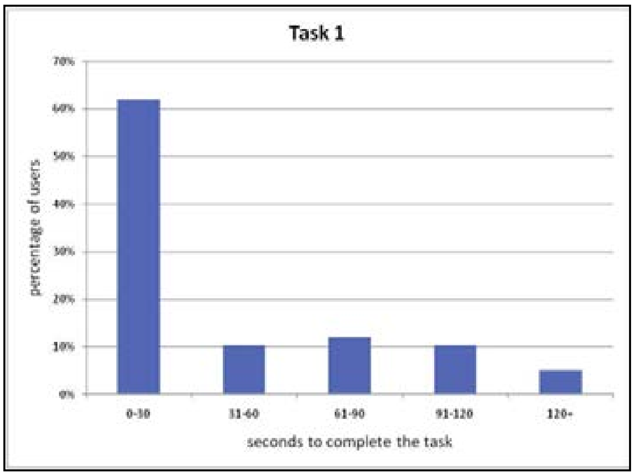


Figure 3. Distribution of times subjects required to complete Task 1 (excluding those who were unable to complete).

Most subjects were able to accomplish the task in less than 30 seconds; however, over 30% of the subjects required 31 – 120 seconds. (Note that two minutes can feel like a very long time when trying to switch on the heat.) About 26% of the subjects were unable to accomplish the task at all and are not displayed in this Figure. The results shown in Figure 3 (and other results not shown here) demonstrated that the methodology produced a wide range of measured abilities of the subjects to perform the task.

A second requirement of the task-based methodology is the ability to quantitatively differentiate levels of usability among thermostat interfaces. Figure 4 displays the range in elapsed time to completion for accomplishing Task 1 with the five thermostats. The times for *not* completion are shown in red; this is where the subject mistakenly believed that he or she had completed the task or gave up. The times are averages based on about 12 subjects tested on each thermostat. The Figure demonstrates that the task-based methodology and the metric permitted easy differentiation among the thermostats. The average time to accomplish Task 1 for Thermostat E was roughly eight times longer than for Thermostat A.

Thermostats A and B were clearly superior (for this task) because the subjects were able to accomplish the task quickly and nearly all of the subjects successfully completed the task. In contrast, the subjects accomplished Task 1 on Thermostat D relatively slowly and a significant fraction were unable to complete it at all. Both Thermostats D and E had hinged covers concealing the controls, which many subjects either did not recognize or were unable to open. This illustrates how small design differences can have large impacts on successful operation of a device.

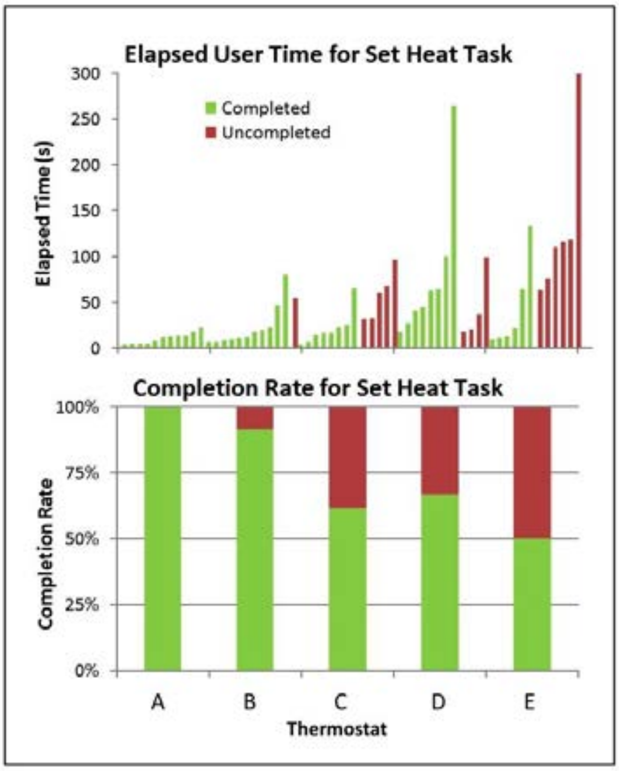


Figure 4. The subjects' completion times and completion rates for Task 1.

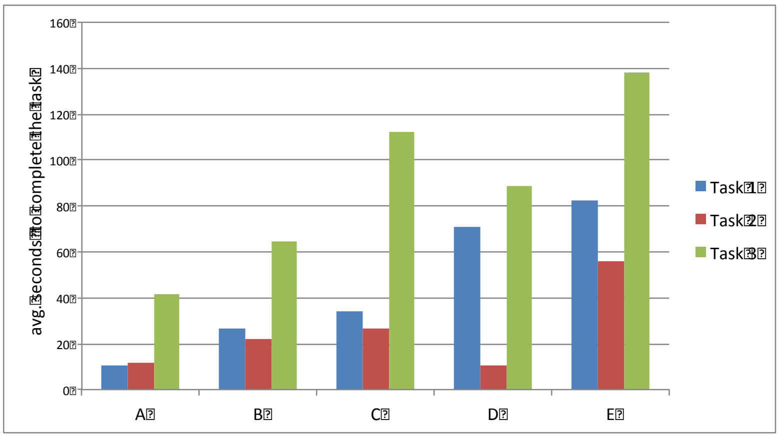


Figure 5. Average time to complete Tasks 1, 2, and 3 for the five thermostats.

The results were similar for other tasks. Figure 5 shows the average elapsed times for Tasks 1, 2, and 3. A wide range in average completion time was observed in all three tasks. The ranking of thermostats changed slightly depending on the task but, in general, a model with long average completion times for one task had long completion times for other tasks.

The average elapsed time for completion is an attractive metric, with robust results; however, it may be misleading when many subjects fail to complete the task because those measurements must be omitted in order to avoid a nonsensical solution (e.g., infinity). We therefore developed a hybrid metric, combining both elapsed time to complete and successful completion of the task. We also wanted the metric to be bounded, that is, from 0 to 1 so that results from different tasks were more easily comparable. These features make the metric simpler to interpret. The metric, "Time and Success Metric" is based on a logistic function to capture the features described above.

The time and success metric, "*M*", is calculated as follows on a per-trial basis:

$$M_i = \frac{2s}{1 + e^{x_i}}$$

where

$$x_i = \text{distinguishing variable for each metric}$$

$$s = \begin{cases} 0, \text{if subject failed to complete task} \\ 1, \text{if subject completed task} \end{cases}$$

Note that M_i will always be normalized between 0 and 1. The success rate variable, *s*, also always falls between 0 and 1. It can be a binary variable (where *s* = 1 if the task is completed and 0 otherwise), have multiple values for partial success (e.g. if the task has several subparts that can be completed successfully), or be a continuous variable that measures percentage of task completion.

The metric combines time on task with success of the trial in an intuitive manner: if the task is not completed so that *s* = 0, the value of the metric is 0. Intuitively, this means that if the task was not completed, it should not matter how long the user spent attempting it; it is still a failure. If, on the other hand, the task is completed successfully, then the time on task weighs into the metric. For example, a shorter task duration will yield a higher value of M, a longer task duration will yield a lower value of M, and an uncompleted task will set M = 0.

The results for the three tasks combined, using the time and success metric (and k_1 = 50) are shown in Figure 6. The Figure displays mean values, along with error bars at the 95% confidence level.

Both of the concepts, time to completion and success to complete, are intuitively easy to understand.

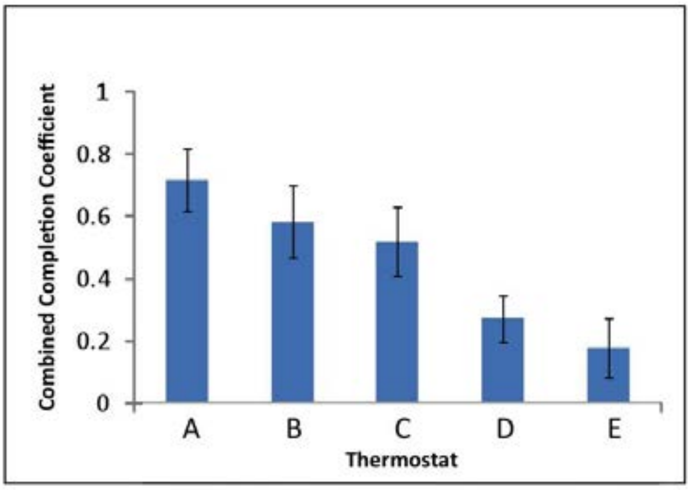


Figure 6. Time and success metrics for the five thermostats based on Tasks 1, 2 and 3. NOTE: figure will be redrawn with correct vertical axis.

Furthermore, they are easy to measure in a laboratory with relatively simple equipment. These features make the task and success metric an attractive metric for quantifying usability.

Discussion

These results suggest that it is possible to quantitatively evaluate the usability of thermostats. These results also suggest that a usability score, based on a combination of tasks, will be a meaningful indicator of overall usability. The results are promising but further research is still needed gain greater confidence in the approach. Some topics for further research include:

- How many people should be on a user test panel and how should they be selected? These questions require guidance from both statisticians and policymakers. On the statistical side, we need large enough test panels to attain satisfactory confidence in the results. Policymakers need to decide to what extent elderly, handicapped, colour-blind, and non-English speakers are included.
- Repeatability is a key requirement for any test procedure. We have not yet confirmed that the test results can be duplicated in other laboratories.
- Can repeatability be improved by testing subjects on a “reference” interface in addition to the product under test? A reference interface would make it possible to calibrate the panel of subjects and potentially lessen distortions caused by non-representative sampling.
- Does the test procedure stifle innovation? Thermostats are undergoing rapid changes in both technologies and requirements. For example, can this test accommodate voice commands or visual cues?

Energy Star is addressing many of these issues [7] because it intends to include a usability criterion in its next specification for programmable thermostats (which it calls “climate control devices”). To our knowledge, this Energy Star specification is the first application of a quantitative usability requirement for the controls of a device.

Application of this Approach to Other Products

This approach, as well as the time and success metric, can be applied to other devices where poor usability may impede energy-saving behaviour. Modern lighting controls–especially those with several features–in commercial buildings suffer from usability problems. Occupants are often frustrated and unable to easily obtain the desired illumination conditions. It is easy to construct a list of representative tasks for lighting controls. This list would include:

- Determine status of lights
- Switch light on
- Switch light off
- Identify if light has dimming capability
- Dim light to about 50%
- Determine if light is connected to a sensor

These tasks might seem trivial yet Figure 7 illustrates the diversity of controls (and the complexity of actions needed to accomplish the tasks) that a user will confront.

Figure 7. Six lighting controls found in commercial buildings.

For Task 3, dim lights to 50%, the procedure is different for almost every control (and not always obvious). The time and number of actions varies from a single rotating action to multiple button pushes. One must also take into consideration that there will be more first-time users than with residential thermostats.

Heat pump water heaters require sophisticated controls so as to ensure maximum efficiency while meeting hot water needs. Figure 8 shows the controls for three commercially-available heat pump water heaters. Incorrect settings of these controls can lead to significantly higher energy consumption without the consumer being aware. The likelihood of incorrect settings is high because controls are confusing and occupants are not familiar with this new device. On the other hand, the use situation is different from thermostats because users are likely to select their preferences once and leave them for long periods. This may encourage users to devote more time to initial settings. (Field research needs to verify actual operating patterns.)

Figure 8. Controls for three residential heat pump water heaters (source EPRI).

Designing clear user interfaces for “smart” products will become a critically important requirement for ensuring energy-efficient operation.

Conclusions

The controls of energy-using products are becoming increasingly sophisticated in order to provide both more features and increased energy efficiency. Ironically, as the devices become “smarter”, the quality of the interface between the device and user rises in importance. A “smart” device will remain efficient only as long as the settings and other parameters allow it to be. Thus, the degree of “usability” is becoming an element of energy efficiency similar to other physical characteristics like insulation. To date, however, there has been no way to measure usability.

The digital programmable thermostat relies on user input to set operating parameters. Many users of programmable thermostats have been frustrated by the controls and, in some cases, have been unable to accomplish basic tasks necessary to effectively operate the devices. The results are thermostat settings that potentially lead to higher than necessary energy use, often without the knowledge of the user.

We developed and tested a procedure to quantify the usability of thermostats. The measurement of usability is based on the assumption that the essence of usability can be captured by a collection of representative tasks. We demonstrated that a relatively simple laboratory set-up and test procedure could collect adequate data for assessment. A range in human abilities in accomplishing a task was easily discerned. The same tests also revealed wide variation in the subjects’ ability to accomplish the same task on different thermostats. Thus it was possible to discern thermostats that were more effective than others.

We created the “time and success metric”, which appears to reflect the usability of a task. The data required to calculate the time and success metric are easy to collect and reasonably unambiguous. A second feature of the time and success metric is that metrics from different tasks can be combined through addition and an overall usability “score” calculated.

Many of the usability problems identified in thermostats appear in other products. We showed two examples, controls for lighting and heat pump water heaters. Other products, such as televisions, also deserve attention. Further research will still be needed to refine the approach and the metric; however, we believe that they are already suitable for quantitatively evaluating the usability of products. Manufacturers can use this procedure as a design tool and regulators can establish minimum usabilities for appropriate products.

References

[1] B. Nordman, A. Meier, and D. Auman, “Fixing the Power Management Controls Problem,” in *ACEEE Summer Study on Energy Efficiency in Buildings*, 2002.

[2] ISO, *Guidance on Usability*. Geneva: International Standardization Organization, 1998.

[3] B. Nordman, *Power Control User Interface Standard — Final Report*. Berkeley (Calif.): Lawrence Berkeley National Laboratory, 2002.

[4] A. Meier, C. Aragon, T. Peffer, and M. Pritoni, *Thermostat Interface and Usability: A Survey*. Berkeley (Calif.): Lawrence Berkeley National Laboratory, 2010.

[5] H. Sachs, *Programmable Thermostats*. Washington, D.C.: American Council for an Energy Efficient Economy, 2004.

[6] A. Meier, M. Pritoni, C. Aragon, D. Perry, and T. Peffer, “How People Actually Use Thermostats,” in *ACEEE Summer Study on Energy Efficiency in Buildings*, 2010.

[7] U.S. Environmental Protection Agency, “ENERGY STAR® Residential Climate Controls Draft Specification Framework –Performance-Based Usability Requirements,” 30-Nov-2010.

Food-Related Eco-visualizations – from Intent to Action

Erica Löfström, Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology (NTNU)

Ida Nilstad Pettersen, Department of Product Design, Norwegian University of Science and Technology (NTNU)

Abstract

Evironmental concerns are increasingly becoming important as a symbolic issue. The paper explores the potential role of using visible symbolic qualities (VSQ) of resource saving measures in influencing food-related consumption. The study is explorative and based on the results of focus group studies in which the informants are presented with concepts of eco-visualisations of food-related everyday activities, and encouraged to elaborate upon the potential role of such visualisations. The aim is to contribute to ongoing projects investigating the role of technology in design to promote sustainable household practices.

It seems the potential use of these mechanisms is well worth pursuing. Also, the potential impact of the mechanism are related to the intimacy of the data exposed and the degree of publicness of the visualisation. Therefore, these factors should be investigated further. As the symbolic qualities that are to be activated by these visualisation techniques are intimately related to – and dependent on – existing norms, these strategies should be further investigated in relation to, for instance, the emergence of moral landscapes.

Acknowledgements

This paper is part of an ongoing project called “MetKit: the Metabolism of the Kitchen – Situations of Opportunity in Everyday Life” (founded by Swedish FORMAS). It is also part of a research project involving an interdisciplinary group of researchers working with the Municipality of Trondheim in creating a carbon-neutral settlement. For a more extensive version of this paper and results, see the Conference Proceedings of European Council of an Energy Efficient Economy 2011 (ECEEE) [1].

Introduction

As noted in recent debates on climate change, it is obvious that we cannot maintain the lifestyle in wealthier countries, at the same time as meeting internationally-set goals of fighting “global warming”. In pursuing international goals to address climate change, carbon-neutral residential areas are being built all over the world [2]. These new residential areas often do not live up to their set goals, which is often related to the users’ carbon-intensive lifestyles [3]. Hence, it is not a successful strategy to have people move into a carbon neutral area whilst maintaining the same lifestyle. It has also been shown that we cannot rely on technology-focussed solutions only to address climate change. Policies and research, however, often focus on technology and buildings as solutions for the problem of over-consumption. There are many reasons for this, of which one of the most pertinent is that user behaviour is both difficult to control, and to predict. One problem is that these future settlements are planned within a system in which ‘excessive’ consumption is regarded as a central point within economic reproduction [4:p3]

Numerous examples show that, when residents are not involved in the process of co-creating residential areas with ambitious environmental profiles, they will not adjust their lifestyle in accordance to the set premises [5][6]. Indeed, even if the residents intend to change their behaviour, this has been shown not to translate into actual practice. Since carbon-neutral living is still a utopia, there are no simple instructions to follow for people to live carbon-neutral lifestyles. In an attempt to achieve user participation in a particular project, i.e. carbon neutral Brøset, one part of a more extensive research group targets the particular area of participation. One aim of this part of the project is to find which strategies may work in supporting the future residents in increasing environmental consciousness and obtaining and maintaining sustainable household routines. Therefore, FGIs have been performed and some results of these are presented in this paper[1].

The paper considers food-related household activities and explores how VSQs can support household members in developing and maintaining sustainable everyday household routines. The interview data is used to explore food-related visualisation concepts. The analysis places these visualisation methods in the setting of the development of an actual area, carbon-neutral Brøset, which is to involve major changes in the residents' lifestyles.

Households' everyday resource use

It is a known fact that behaviour is difficult to influence. One explanation for these is that many actions are taken as part of integrated routines that are not reflected upon. At the same time, it is known that people are involved in 'making their environments conform to an ideal order of society' [7:p82] (interpretation of [8]). When conforming to the ideal order of society – as it is being perceived – we are also making visible statements about our home [8:p69] and stating who we are. Naturally, in a world of changing ideals and orders, new practices indicating a 'reconfiguration of social ideals and orders' can and will emerge [7:p82]. As an example, moral landscapes have emerged locally within society, for instance in residential areas with a particular "green" profile [9]. As a rule, however, such moral landscapes do not emerge simply because a project has a stated intent. The emergence of such 'local reconfigurations of social ideals and orders' involve the recognition of the symbolic significance of households' everyday activities. Hence, it is possible for environmentally-beneficial practices to acquire symbolic significance, including restriction of consumption [10]. It has also been suggested that domestic technologies script their users' behaviour. By acting as 'moralising machines', by showing new possibilities for improving everyday practices et cetera [11]. Also, these technologies configure the knowledge and skills of those who use them, 'structure the moral landscape in which actions have meaning' - to such an extent that new technologies are 'enmeshed in a landscape of moral and social distinction' and their development has the effect of 'reconfiguring that terrain'. [7:p83]

According to Shove [7], six different mechanisms which potentially influence the level of consumption have been isolated. For this paper, two are relevant; 1) social comparison, which means that people are marking social boundaries by the consumption of certain goods and 2) the creation of self-identity, meaning that people define themselves through the messages they transmit to others, through their goods and practices. They manage appearances, thereby creating and sustaining self-identity. None of these mechanisms fit areas of inconspicuous (hidden) consumption and are not helpful in terms of understanding the use of appliances and grocery shopping. [10]. Shove and Warde [10:p6] suggest that:

> 'A distinction should be made between a world of relatively individualized consumer behaviour involving the selection of discrete and visible commodities and a muddier world of embedded, interdependent practices and habits, probably better explicable in terms of background notions such as comfort, convenience, security and normality'.

However, existing norms are likely to work both as obstacles and success factors, and a combination of these may explain why some interventions are more likely to be translated into action than others. But environmental concerns are becoming more important. Fear of being perceived negatively may be a driver for behavioural change. Equally, the possibility of getting "cred" from others may well be a relevant driving factor. Behaviours depend partly on the economic situation of a household. Wealthier households may more likely act in accordance with symbolic issues while economically-challenged households to

[1] The Focus Group Interviews were performed and analyzed by Erica Löfström

larger extents, prioritise economic factors [12:p1333]. It also partly depends on social norms, which are re-negotiated in the process of the forming of moral landscapes.

In order to be able to influence even inconspicuous consumption using the re-emergence and emergence of moral landscapes supported by new moralising technologies, we can see it in combination with the co-emerging restructuring of the symbolic significance of everyday activities. One way is to try and redefine these practices by lifting them from the world of interdependent practices and habits and instead placing them in the world of more or less 'individualised consumer behaviour'. These types of practices involve the selection of discrete and visible commodities [10:p6]. This would make them more suited for being subject to the mechanisms which potentially influence consumption.

Changing everyday behaviour

Jelsma suggests that we revise our view on daily practices [11:p103]. Even though the role of personal values in influencing pro-environmental behaviour has gained increased attention [13], however, the advantages for an individual to adhere to a new lifestyle will be interpreted differently by every individual. In addition, the environmental consequences of practices are often unclear or invisible to individuals.

Kallgren et al [14] have stated that peoples' behaviour will conform to the dictates of a relevant norm under conditions of *normative focus*. Equally, a particular social norm is unlikely to influence behaviour unless it is focal [15]. However, the term norm has two meanings; it can refer to descriptive- (what is commonly done) or injunctive- norms (what is commonly approved or disapproved). Also, norm-focussed procedures will be more successful in producing desirable behaviour if the relevant norm is injunctive [16] [17] (see also[14]).This means that behaviour may be influenced mainly by injunctive norms but also by descriptive as long as those norms are conspicuous (focal), i.e. measures visible to are more likely to be successful in the domain of household energy use. Also, measures signalling wealth are easier to sell [12]. When our everyday behaviours are conflicting with social norms, a negotiation between their disadvantages and short-term reinforcements occurs [18]. A cognitive dissonance may push us towards breaking habits, *or* keeping them and instead adjusting personal long-term goals. As behaviours and practices are results of social norms, it has been argued that the exploration of alternatives should happen at a community level [19]. This includes the emergence of moral landscapes as the one that will hopefully develop within the planned carbon neutral settlement of Brøset.

However, the formation of new habits requires the breaking of old ones. Automatic behaviour must be raised from practical to discursive consciousness, i.e. 'unfrozen' [20]. Providing feedback can help breaking habits by directing attention towards resource use. Feedback can activate motives that promote users into energy curtailment behaviour [17]. According to Kluger and DeNisi [21], feedback interventions change the 'locus of attention', thereby effecting behaviour [21]; see also [19]). Also, feedback is more effective the more immediate it is [22]. Fischer [17] concludes that the most successful interventions are those providing feedback frequently and over a long period of time, using appliance-specific breakdown combined with clear, appealing presentations. However, not everyone will have the same motives for wanting to change. Different persons may have different rationalities that are relevant for them in relation to certain activities. Also, the same person may be motivated by different rationalities in different contexts. [23] However, which rationality will dominate may be influenced by the emergence of moral landscapes.

Eco- and energy-visualisation concepts have their origin in the fact that our everyday actions are particularly hard to (permanently) influence, as these routine behaviours are largely automatic and thereby invisible, i.e. inconspicuous. The connection between a particular behaviour and its environmental consequences is similarly invisible, especially as it pertains to electrical energy, which is itself invisible to the eye. The origins and background of food and other products, including means of production and transportation, are not visible in supermarkets, nor at home, which can result in these aspects not being reflected upon. This could partly explain why pro-environmental attitudes often do not translate into actual changes [24]. However, this connection can be actualised by means of feedback at the moment a decision is made. The feedback can be in the form of (artificial) visualisation using technology or other methods. This way, the discrepancy between willingness to act sustainably - for example, shopping for “green” groceries - and actual behaviour, can be bridged [6]. This may well be dependent on the norm connected to the actual behaviour in the particular setting.

Hence, we could strengthen the connection between attitudes and actual behaviour by striving to visualise use and production of food. This would enhance the connection between natural resources and use [6] and is likely to be influential if it is associated to in particular injunctive, but also descriptive, relevant norms. It may also contribute towards limit the consumption of resources, causing a smaller carbon-footprint per household. However, although such visualisation technologies have proven to be effective, these concepts and technologies risk gradually becoming self-evident, hence invisible through the process of domestication of technology. The domestication process involves phases by which any technology eventually becomes familiar to its users. The problem is that once the user has fully implemented the new technology, thus given it meaning and a more permanent position (mental or physical) in the household, it has also become virtually invisible. Then, the consumption it was intended to visualise again sinks into the world of inconspicuous consumption. Therefore, is not possible to visualise resource use-related behaviour once and for all. Visualisations need to be flexible both in relation to rationalities of people (in different situations and contexts) as well as flexible over time. They need to challenge the domestication process; continuously de-domesticating it [6], unless the visualisations or what they communicate are incorporated in new routines, and succeed in changing the conventions for a given activity. Interestingly, the inconspicuous consumption can be made conspicuous by means of visualisation, which is a strategy for placing them in the world of ‘individualised consumer behaviour involving the selection of discrete and visible commodities’, which is easier to influence.

Results of the Focus Group Studies

Users may act upon different rationalities in their inconspicuous consumption, but these rationalities are more likely to be put into practice when it comes to more conspicuous consumption. This study attempts to lift some food-related everyday activities towards the more focal consumption by means of eco-visualisations concepts. The results are analysed using theories on households’ everyday resource use and means of breaking habits. Next, the choice of the kitchen as an arena is outlined and the method described.

Food and kitchen-related Activities

Studies reveal that embodied energy from the consumption of goods and services is as significant as domestic energy consumption. According to EEA, approximately one third of households' total environmental impact is related to food and drinks [25]. Conscious food consumption is especially important for a sustainable lifestyle since it holds great potential for improved energy efficiency and life-style change. The high density of technical equipment, in combination with the considerable impact of food consumption, pinpoints the kitchen as an important arena when studying households´ energy use. Another reason for studying the kitchen is that it does not constitute a static household area or design function [26]. Due to its changing past, it can be assumed that this arena may still change considerably. However, the routines related to food and beverages do not only involve actions performed in the household, but include all actions performed as everyday routine. In this study, however, “eating out” is not included in the analysis - only activities related to grocery shopping and kitchen-related activities.

Method

Four FGIs with young adults[2] have been performed focusing on the participants’ view on their future lifestyle and possibilities for change. Also, two other FGIs[3] with people aged 24 to 84 in various family

[2] 5-8 high school pupils/each + interviewer The FGI with young adults lasted for approximately 1 hour 40 min each. Ages of pupils ranges from 16-18.
[3] 5-8 persons/each + interviewer

situations, were gathered, discussing future residential areas and lifestyle. As part of these FGIS, strategies for using VSQ of consumption in relation to the kitchen as public arena were explored. As this concept has not so far been used strategically to influence peoples' behaviour and choices, our focus was mainly to find out which aspects were of importance – and should be considered – in relation to using VSQ of resource use. Our focus also uncovers which strategies may be more interesting to consider in developing the concept further. This is mainly done by investigating which strategies the focus group participants suggest (in the mixed FGIs) and gathering reactions to some visualisation concepts related to everyday grocery shopping that are presented to the participants of the FGIs with young adults. The empirical data represents an initial mapping of relevant aspects to be considered when strategically using VSQ of consumption to influence lifestyle changes in future carbon-neutral settlements.

Mixed Focus Groups

In the mixed focus groups, the participants were asked to imagine living in the future carbon-neutral residential area (Brøset). They were to discuss what issues would be supportive in obtaining lifestyle changes. One idea that was introduced was that there should be common arenas included in this future residential area. In these arenas, people could meet and support each other in striving to live a carbon-neutral life. The FGI participants found the kitchen to be of particular interest as it could more easily be shared than other functions of the home, and that people would then have a common meeting ground evolving around the consumption of food in households. This would be an interesting way of making activities of individual households at least partly focal as they would take place in a shared arena. This increased conspicuousness would make households more likely to be influenced by injuctive and descriptive norms [16][18][14]).

The older participants[4] of the FGIs pointed to some aspects regarding the 'moral' aspects of food consumption. They perceived it as problematic that people seem to be more or less "unaware" of the fact that food is not only consumed, but also needs to be produced.

According to the FGI participants', people would be more careful with their consumption of food if they were confronted with its origin. One simple way of doing this could be to include kitchen gardens in the area, so that these would visualise the connection of food being grown and produced:

> It is very important to have such centres where (children) can gain an understanding of the fact that not everything is produced in factories. (Siv)

In addition, these older FGI participants suggest that a mix of different generations in the residential area would be beneficial, and offer to be part of helping the young in understanding the origin of the food. Also, the younger participants of the mixed FGIs were interested in the potential of introducing these aspects:

> I think this is very important. I think it's important to have some sort of relationship to how much work it takes to create something like that. In other words, people throw away too much food now, that's one of the major problems. People don't have any relationship to what it represents. (Maria)

It would also, as an effect, be less accepted amongst the residents if it became obvious that you were wasting natural resources when throwing away food or over-consuming. In addition, having a common kitchen, could involve people seeing your "waste" by use of strategic visualisations, resulting in a discrepancy of the ideal order of society. It may work as a possibility to show how good you are at consuming smarter, promoting focal injuctive norms. In addition, the design of such a common arena could include the visualisation of resources used (feedback) for each household, hence striving to make people aware of how their private consumption meets up to the total of the residential area; promoting descriptive as well as injuctive norms. However, it was not suggested by the FGI participants that others would be presented the data of private households. This was considered to be too intimate information. However, each household would know their own consumption and should be able to compare themselves with for example the average consumption of neighbours. A version of this would be the visualisation of how "well" the residential area is doing compared to other residential areas. This would be a way of

[4] Some were already retired and some were soon to be retired.

boosting the common identity of the residential area, resulting in a sense of common pride that would inspire them to further reductions in waste of natural resources such as food:

> People in this neighbourhood have a different lifestyle, but they sure seem happy. (David)

This reference to the development of a common identity is an example of the interrelation of taking the inconspicuous consumption which is part of the world of the 'muddier, interdependent practices and habits' and instead placing these practices in the world of more or less individualised consumer behaviour. This would make this consumption suitable for mechanisms which potentially influence the level and type of consumption, such as personal identity driven by injuctive norms, and social comparisons driven by descriptive norms. It would also, if combined with flexible feedback based on real consumption, possibly be less likely to become domesticated. In conclusion, the mixed FGIs indicate that designing common arenas' where the visualisation of shared, but also private, aspects of food consumption may present the possibility to make the publicly 'invisible consumption' visible. This would make it more likely to comply with the norms of the planned moral landscape of Brøset. Also, a mix of generations could increase the effect of the visualisations of the origins of food and resources.

Focus Groups with Young Adults

By gathering existing data that is part of products' digital footprint generated through supply-chain management, a product's environmental impact can be calculated and compared [23]. The paper handles conceptual means of visualising these calculations; it is not discussed how these calculations are made.

Once a person's impact on the environment is determined, for example by comparing the contents of their shopping trolley with that of the 'average' consumer (descriptive norms), this information can be visualised for the shopper. This does not only help comparisons on price and other preferences but also on environmental impact, for example by calculating the trolley content's carbon footprint. In addition, this information can be visualised for other shoppers, promoting injuctive as well as descriptive norms by making (inconspicuous) consumption visible.

In perceiving the concept of using VSQ of consumption related to food, we decided to do additional FGIs[5]. In these FGIs, examples of existing prototypes, and concepts 'invented' by the interviewer, were presented. The prototypes presented were the 'Morally Concerned Teddybear[6]', a 'Carrot Bag' and the 'Reflective Surface'[7] (Fig 1; Fig 2). Other concepts were also presented, such as a shopping trolley which changes the colour of the handle depending on the total environmental load of its content. The intent of introducing these concepts to the participants of the FGIs was not to determine the effectiveness of particular visualisation technologies, but to gather reactions on some "eco-visualisation" concepts. By analysing these reactions, an initial mapping of relevant aspects to be considered when VSQs of consumption are strategically used to influence everyday activities is presented.

The visualisations of a products' environmental effects, as that of a discrete "reader" being used to compare different products and give hints to the customers was considered both potentially interesting and unproblematic by the FGI participants. This reader could be included in a version of the shopping terminals that are already being used in some grocery stores in order for the customers themselves to be able to perform the scanning of products and paying electronically. Also, the possibility of discretely competing with an 'average customer' was appealing to the young adults.

> That may also be a good thing, because in a way you like others to see that you are buying the good products. (Anna)

[5] Four groups with 5-8 Young Adults (16-18 years old) met on one occasion each exploring sustainable lifestyles and ways to achieve changes in everyday life. Each Focus Group meeting lasted for approximately 1 h 40 mins.
[6] The 'Morally Concerned Teddy Bear' assists you while shopping for groceries by communicating to the child about products, for example starting to cry if you choose the environmentally "bad" alternative. (Concept and Prototype: Interactive Institute).
[7] Developed by the Interactive Institute, Sweden.

I'm sure it's smart, because people don't want to be perceived as being bad at choosing groceries. That is probably what you care most about, yes (that others can see what you do…).[8](Anna)

Of course it would make a difference/have an influence. (Beathe)

Yes, it will influence you if others can see the content of your bag. (Anna)

Yes (all agree and laugh)

Fig 1. Reflective Surface is a platform for raising awareness of the background of food. The aim is to visualise complex data from life cycles in a simple and intuitive manner, and it has a graphical language that aims to help the consumer to see what products have a larger climate impact. (Photo, Concept and Prototype: Interactive Institute).

However, when introducing the possibility of revealing this information to others in addition to the consumer herself, this was considered potentially more effective, but also, for some participants "worrying". It was clear that the degree of "publicness" of the visualisations was of importance:

I think it may feel a bit weird to walk around in the store with such a teddy bear (…) but if it would have been a small gadget or something, it would have been okay. (Bjorn)

One thing is that you are able to see it yourself, but I don't think I would like for others to see it… One thing is that you know for yourself, but ... not that you should have to be ashamed of what you buy. (Anette)

More discrete indicators were considered less effective but also unproblematic. The concept of revealing to 'the whole store' and possibly to people meeting you on your way home, was met with two different fractions in the FGIs. Surprisingly, it did not have to do with any aspects of "privacy" or "integrity" but emanated from whether the participants perceived themselves as more or less likely to act in a politically

[8] Focus Group With Young Adults

“correct” way. The ones who pictured themselves as doing the “right thing” would be proud if others could see their behaviour, while those picturing themselves doing the less positive would be embarrassed:

> And you would be so proud of yourself, at least I would be… It is a bit judgmental. (Bjorn)

> Naturally, (you) don’t want to make a bad impression. (Anna)

However, the discussion came up that you may sometimes still want to buy these other, “bad” things. Then, you might avoid the store where you would risk being exposed as a person not acting in line with norms and choose a different store that lacks these concepts promoting VSQ of consumption. This complementing store without the visualisation techniques is humoristically referred to as the “the shame store”. Then you would do your “bad” grocery shopping in this one, whilst doing your main shopping that is in line with the norms of the moral landscape in the one with the visualisations:

> It depends on what you were going to buy then, when you would (buy “good” products) you would go to that store. If you know it’s going to look bad, you go to the other one. (Anders)

> (Laughter from the group)

However, if these concepts were not communicated in the right way, it may be stigmatising to act environmentally-aware. Then there is a risk of these concepts having the opposite effect:

> I don’t know… I could actually go both ways, because if I get the green bag[9] and as such you might in a way be almost branded, so that … it can be both negative and positive - I believe one has to in a way promote it using the right words. If not, it may have the opposite effect and actually have a negative influence on what’s environmentally friendly. (Anette)

Fig 2. The Carrot Bag makes its user aware of environmental impact from food consumption by recording and visualizing its content. (Photo, Concept and Prototype: Interactive Institute).

According to current norms it is not perceived as solely positive to shop in an environmentally-aware way. This is, of course, yet another challenge for these mechanisms to have any influence on actual behaviour. Also, as has previously been stated, households which have different co-existing rationalities that are more or less dominant when it comes to the use of energy within the household (Löfström 2008) are likely to display the same qualities when shopping for groceries. How these concepts are communicated, is of

[9] Here the concept of getting your shopping bag (plastic or other) to take home branded so that people would see if you have bought more “sustainable” products (green bag) or “ less sustainable” products (red bag).

course dependent on the moral landscape which they would be part of when doing their grocery shopping. Are the communicated aspects of these visualisations in line with existing norms in the context? If not, the symbolic qualities of consumption that are visualised risk having the opposite effect by counteracting its own intended influence.

Supporting this, the ‘proud’ group was dominant in two FGIs while the ‘ashamed’ group was dominant in the two other groups of young adults. It seemed that the groups tended to imagine doing whatever was assumed first within the group. This could be interpreted as support of the necessity of combining the introduced VSQs of consumption with that of ‘moral landscapes’ in which a certain behaviour in particular spaces may be judged more or less appropriate [27]. The FGIs with young adults show that the concept of using VSQ of consumption as a means of influencing shopping may be both effective and interesting, even amongst those who would be ashamed of their own behaviour. In fact, they would not mind trying it in real life even though some were more worried about having the results revealed in public. Hence, using norms as part of a moral landscape could be a strategy to strengthen and develop the concept further.

Conclusions

The data collected indicates that using both private visualisation techniques, aiming at activating norms at the individual level, and public visualisation techniques, aiming at activating norms at the social level, may well be relevant factors to consider when designing for influencing households’ energy and resource use. Using eco-visualisation as a means to unfreeze automated everyday behaviour by changing the locus of attention could well encourage individuals to make visible statement of individual and social identity.

Furthermore, concerning the possibilities of strategically using VSQ in planning and architectural design, the kitchen and food production seem to present a suitable starting point for working with mechanisms related to social norms. A combination of private (individual) and public (social) means of making food-related activities less inconspicuous and the visualisation of household behaviour-related resource use and production seems to offer a promising arena for the development of innovative new designs. In general, the kitchen offers an arena suitable to use as a starting point in creating a shared positive identity, as the food-related activities are not considered to be too intimate. However, it seems that every-day consumption on the household level is too intimate to be suitable for public visualisation, but that a public visualisation of average and comparative consumption may be suitable.

Concerning the issue of which types of strategies and visualisation techniques might be applicable in the design domain, the results indicate that it would be possible to at least partly visualise individual behaviour at a public level. This could be due to that grocery shopping activities are placed in a different, more public context. However, the suggested escape to the “shame store” in which you can do your “bad shopping” indicates that there are limits to public visualisation of individual consumption. One solution could be to make only positive indicators of behaviour available at a public level. Another possibility could be to make the individual indicators more discrete so that people would have to approach each other to find out more about each others’ consumption. Even though the possibilities and limits to the strategic use of using VSQ to influence consumption need to be further investigated, one conclusion is that food-related activities seem to hold great potential.

However, it is important to work on the way these concepts are introduced and communicated to the public, as rebound effects are a potential risk. It is crucial to explore the possibilities to encourage the emergence of rules and regulations for moral behaviour [28], eg by using the theoretical approach of moral landscapes.

References

[1] Löfström, E. and Pettersen, I.N. 2011 (forthcoming), *Public and Private Feedback: Food-Related Eco-Visualisations promoting visible symbolic qualities of consumption*. In 2011 Summer Study proceedings of the European Council for an Energy Efficient Economy (ECEEE): Energy efficiency first: The foundation of a low-carbon society

[2] Broset project website, 2011, available at http://brozed.wordpress.com/project-examples/

[3] Löfström, E. and Palm, J. 2010, *On the Invisible Socio-Technical Systems: The Great Unknown*, the International Journal of Power and Energy Systems, ACTA Press, Canada

[4] Slater, D. 1999, *Themes from the Sociology of Consumption*, in the Reader of Consumption, Everyday Life and Sustainability

[5] Gamst, L 2007, *Bedre IntressentInndragelse: Inspiration til byudviklingsprosjekter*, ISBN 978-87-992124-0-8

[6] Löfström, E. 2008, *Visualisera energi i hushåll—metoder att synliggöra sociotekniska system och individ- respektive artefaktbunden energianvändning*. Dissertation Linköping University

[7] Shove, E. 2003, *Comfort Cleanliness and Convenience, the Social Organization of Normality*, Berg Publ., Oxford

[8] Douglas. M. 1984, *Purity and Danger: An Analysis of the concepts of pollution and taboo*, London, Routledge

[9] BedZed website, 2011, available at www.zedfactory.com

[10] Shove, E. and Warde, A. 1999, *Noticing inconspicuous consumption*, in Consumption, Everyday Life and Sustainability

[11] Jelsma, J. 1999, *Toward a sustainable society: the moralizing of machines?,*4S annual conference, San Diego, 27-30 October 1999.

[12] Jensen, J. 2005, *Consumer intertia to energy saving*, in: 2005 Summer Study proceedings of the European Council for an Energy Efficient Economy: Energy Savings: What works and who delivers? pp.1327-1334

[13] Gutierrez Karp, D. 1996, *Values and their Effect on Pro-Environmental Behaviour* in Environment and Behaviour, January 1996 vol. 28, no. 1 pp. 111-133

[14] Kallgren, C.A., Reno, R.R., & Cialdini, R.B. (2000). *A focus theory of normative conduct: When norms do and do not affect behavior*. Personality and Social Psychology Bulletin, 26, pp. 1002-1012

[15] Cialdini, R. B., Reno, R. R. and Kallgren, C. A. 1990, *A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places*. Journal of Personality and Social Psych., 58(6), pp. 1015-1026

[16] Cialdini, R. B., Kallgren, C. A. and Reno, R. R. 1991, *A focus theory of normative conduct: A theoretical refinement and reevaluation of the role of norms in human behavior*. Advances in Exp. Social Psych.24, pp. 201-234

[17] Fischer, C. 2008, *Feedback on household electricity consumption: a tool for saving energy?*, Energy Efficiency, 2008, 1 (1), pp. 79-104

[18] Reno, R. R. , Cialdini, R. B., and Kallgren C. A. 1993*, The transsituational influence of social norms*. Journal of Personality and Social Psychology, 64, pp. 104-112

[19] Pettersen, I.N. 2009, *Visualising Households' Resource Consumption*. In Proceedings of EcoDesign 2009, 6th Int. Symposium on Environmentally Conscious Design and Inverse Manufacturing, Dec 7-9, Sapporo, pp. 261-266

[20] Jackson, T., 2005, *Motivating sustainable consumption: a review of evidence on consumer behaviour and behavioural change*, Energy Environment (2005), Volume: 15, Issue: January, Publisher: A Report to the Sustainable Development Research Network, p. 170

[21] Kluger, A. and DeNisi, A. 1996, *The Effects of Feedback Intervention on Performance: A Historical Review, a Meta-Analysis, and a Preliminary Feedback Intervention Theory*, Psychological Bulletin 1996, 119(2), pp. 254-284,

[22] van Raaij, W.F. and Verhallen, T.M.M., 1983, a *behavioural model of residential energy use*, 'Journal of Economic Psychology, 1983, 3(1), pp. 39-63

[23] Löfström , E. Palm, J. and Gullberg, E. 2011 (forthcoming), *Environmental Consciousness*, Chapter in The International Encyclopedia of Housing and Home, Elsevier Ltd

[24] Vareide, K. and Wilhite, H. 1986, *Encouraging Household Energy Conservation: Have Nordic Incentive Strategies Been Grounded in Research Results?*, Copenhagen: Nordisk Ministerrådet

[25] EEA 2005, European Environment Agency, Report No 11/2005, *Household consumption and the environment*, also available online at http://www.eea.europa.eu/publications/eea_report_2005_11

[26] Bech Danielsen, C. 2010, *Architecture- a mirror of everyday life: Focusing on trends in design and layout of kitchens in the last 100 years*, proceedings of the European Network of Housing Research (ENHR) 2010

[27] Matless, D. 2000, *Moral Geographies*, in R.J. Johnston, D. Gregory, G. Prat and M. Watts, eds. Dictionary of human geography, 4th edn, Malden, MA, Blackwell

[28] Setten, G. 2004, *The habitus, the rule and the moral landscape*. Cultural Geographies 11, 389–415.

Making Smart Appliances for Smart Grids: Flexibility in the face of uncertainty

Dr George Wilkenfeld

Director, George Wilkenfeld and Associates

Abstract

A smart grid needs smart appliances. Unfortunately, there is no agreement on the meaning of either of these terms, and much of the investment in 'smart grids' could be stranded unless appliances can respond to utility load control signals or sense the condition of the grid.

There is no single global standard for communications between energy utilities and appliances. The existence of multiple pathways is itself a market barrier, because products that are compatible with one utility's system may not work in another's, and appliance manufacturers find it too risky to commit to a particular communications strategy that may have only limited takeup.

The ideal way to address these barriers is to develop open standards at the national and possibly the global level. Progress in this direction has been slow, so in the meantime Australian governments have developed a strategy based on flexibility and simplicity, that is compatible with existing systems such as Zigbee and Homeplug but allows for appliances to interact with different systems over time.

The strategy is based on Australian Standard AS4755, which defines a simple demand response interface for air conditioners, swimming pool pump controllers, water heaters using electricity (including heat pump and solar) and charge/discharge controllers for electric vehicles. Australian government are investigating the costs and benefits of making AS4755 interfaces mandatory for these appliances, perhaps as soon as 2011. Several global air conditioners suppliers participated in the development of AS4755 and are confident that they can supply complying products.

The priority appliances have been selected because of their present or projected contribution to peak demand, and their capacity to store energy during periods of low supply price or high availability of renewable generation. Unlike refrigerators or clothes dryers, they are fixed in place and do not move with the householder, so once a communication pathway is established it remains useful for the life of the appliance and the house.

This paper explains the AS4755 demand response interface, and how it interacts with a range of home area network protocols and with smart meters (for which Australia is also developing national standards). It also summarises the cost-benefit case for making the interface mandatory.

The Development of Demand Response Standards in Australia

Electricity demand in Australia is projected to increase at about 2.1% per annum, or 0.7% per annum per capita, over the next decade.[1] This stresses the supply infrastructure, which must accommodate high growth and at the same replace assets that have reached the end of their useful lives.

Much of the added supply capacity will only be used for a small part of the year, when demand on the system is at its maximum. This is largely due to household air conditioning: rising ownership, increasing average power and more use of cooling as summers become more extreme. It is projected that the proportion of Australian households with at least one refrigerative air conditioner (AC) will increase from about 56% in 2010 to 70% by 2020 (Figure 1).

Electricity blackouts caused by residential air conditioning in 2004 made Australian governments acutely aware of the peak load implications of household air conditioning. An analysis of policy options at the time concluded that increasing the energy efficiency of buildings and air conditioners would not have sufficient impact on peak load, given the projected rates of growth, and direct load control strategies were necessary.[2] Since then, the contribution of swimming pool pumps to summer maximum demand, and of electric water heaters to winter maximum demand, has also been analysed (Figure 1: the projected reduction in electric water heater ownership is due to a policy of phasing them out because of their high greenhouse intensity [3]). Electric vehicle charging has also been identified as a future peak load issue, although there are virtually no electric vehicles at present.

Many of the products which have been the focus of demand response interest in Europe [4] are not of great significance in Australia, where most system peaks occur in summer rather than winter. Even in winter peaking areas, some products that are common in Europe are rare (eg heating circulation pumps), and appliances which are a problem in Europe are less so in Australia, because of the relatively mild winters and the tendency to wash clothes in cold water (dryers, clothes washers).

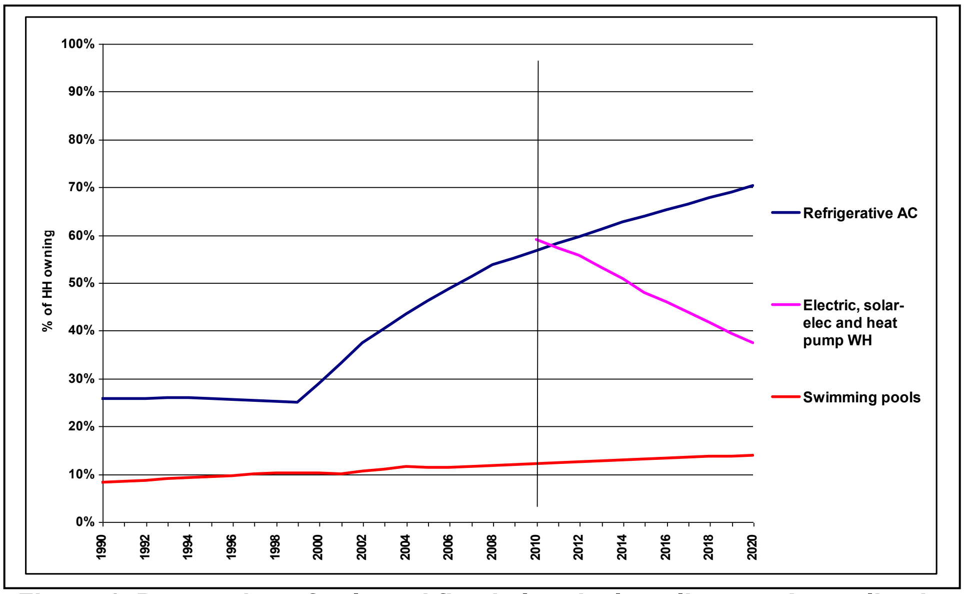


Figure 1. Penetration of selected fixed electrical appliances, Australian households

In early 2005 the then Australian Greenhouse Office (AGO)[1] initiated the Australian Household Electricity Load-Management Platform (A-HELP) project, with aim building a large scale, reliable and low cost demand response capability in the household appliance stock. The author presented a paper on the A-HELP project at EEDAL 2006.[5]. A-HELP was a focus for informal contacts between a number of organisations involved with aspects of peak load, including manufacturers and importers of air conditioners, the operators of electricity distribution networks, home automation system suppliers, professional organisations, university departments and research organisations.

In January 2006 Standards Australia formed a new committee (designated EL-054, Remote Demand Management of Electrical Products), which in April 2007 published AS 4755-2007, *Framework for demand response capabilities and supporting technologies for electrical products*. The standard adopts a three part framework, covering the 'Remote Agent' (which is usually the energy utility, but could be an intermediary such as a demand response aggregator), a 'Demand Response Enabling Device' (DRED) and the Electrical Product (EP). The DRED is actually a set of capabilities and functions, which may be located in a separate physical component, or incorporated into the Electrical Product itself, the electricity meter or some other device.

There are many possible pathways and protocols for communicating between the Remote Agent and the DRED, including wireless, power line carrier and internet-based options. There were (and still are) many views on which of several existing communications standards to adopt, or indeed whether it is necessary to adopt such standards at all, beyond specifying a core set of message requirements.

The Standards committee decided to disentangle these issues by first developing a simple physical interface between air conditioners and DREDs, so manufacturers could begin to sell demand

[1] In late 2007 the appliance energy efficiency and standards programs of the AGO were reorganised as part of the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA), and in early 2010 they were again reorganised as part of the Department of Climate Change and Energy Efficiency (DCCEE).

response-capable products without waiting for resolution of the communications issues. This interface is defined in AS 4755 Part 3.1: *Interaction of demand response devices and electrical products - Operational instructions and connections for air conditioners*.[6] The author presented a paper on this approach at EEDAL 2009.[7].

'Smart Grids, Smart Metering, Smart Appliances' – Why is progress so slow?

Nearly seven years have passed since the AGO (now DCCEE) first identified the demand response problem and began working on a solution that suits Australia's circumstances and priorities. During that time, while work in AS4755 has continued, DCCEE has closely monitored international developments, to assess whether appliance manufacturers in Europe, Asia or the USA were likely to agree on a common approach to demand response or, at least, on a common physically interface. The published reports, while giving some indication of directions [7,8] are too general to form a basis for policy. The lack of focus has been confirmed through direct contacts with appliance manufacturers.

The issue has been given a boost by growing government and utility interest in 'smart grids'. Dynamic matching of supply and demand is one of the main benefits expected from the development of smart grids, which involve simultaneous changes in system 'hardware' (generation, distribution and end use technology) and 'software' (modes of management and control, contractual relations between energy suppliers and users, energy pricing and utility regulation).

It has been accepted in Australia that smart grid development will be largely driven by commercial forces, but governments have acknowledged that some guidance and intervention is necessary, given the scale of investment and the fact that much of it will be made by regulated monopolies.

However, progress on extending the principles of the smart grid all the way to the end point – the appliance – has been disappointingly slow. While smart meters and in-home displays are optional but useful elements of smart grids, *smart appliances* are essential. Without smart appliances even motivated energy users can eventually tire of monitoring energy prices and having to respond manually. Purchasing and enabling a smart appliance is a convenient way to ensure that user preferences are automatically carried out, just as purchasing an energy-efficient appliance locks in energy savings without users needing to think about their behaviour every time they use a product.

Despite the growing urgency, many of the discussions about appliances have an eerie familiarity from three, and even six years ago; the terminology has been rebadged (everything is now 'smart') but there is little evidence of concrete progress. The same few products seem to be rolled out at trade shows (the 'internet refrigerator', the Zigbee-enabled clothes washer) and there has been some useful work on communications protocols [9] but a true mass market roll-out seems to be as far away as ever. While international agencies such as the IEC have now become engaged in the issue [10], agreement on international standards could take many years, if it is possible at all.

One basic problem appears to be one of market failure through *positive externality.* Electricity users, electricity suppliers and other stakeholders would all benefit from the widespread availability and use of smart appliances, but no stakeholders can be assured of gaining enough of the benefit to take the steps necessary to bring this about.

Given the structure of the electricity supply industry, and the fact that smart grid technologies by their nature extend across both energy supply and energy use infrastructure, only governments have the capacity to address this form of market failure. Fortunately, Australian governments appear to be in a unique position to address this.

'Smart Enough' appliances – AS4755

Another basic problem is that there is no agreement on what makes an appliance 'smart', or indeed how smart it needs to be. It is not possible to answer that without reference to the electricity grid and the pricing and regulatory environment where the appliance will be used – what we have called the grid 'hardware' and 'software'. A product that has sophisticated communications and response capabilities may be quite 'dumb' in a supply area that uses different communications protocols or where the electricity price regulator does not allow time of use (TOU) contracts.

AS4755 has deliberately reduced the set of instructions to the 'demand response modes' (DRMs) summarised in Table 1. DRMs may be initiated directly by the remote agent (i.e. Direct Load Control) or by the DRED itself, when pre-set electricity price or other threshold criteria are met. The physical interface (identical for al products) consists of a set of screw terminals or a RJ45 plug. If the extra-low-voltage (32 V DC) circuit corresponding to DRM1 is completed by a relay closure on the DRED, the electrical product enters that mode and stays in it for as long as the circuit remains closed.

To comply with standard AS4755, an electrical product need only be capable of DRM1. The ability to respond to other DRMs is optional, and manufacturers would be free to make a commercial decision whether to provide them or not. However, if a product supplier indicates that a capability is present, this must be verifiable by testing.

DRM4 is intended to make water heaters (electric, solar-electric and heap pump), pool pumps and electric vehicles operate as energy sinks during periods of low electricity price or high availability of renewable generation. For water heaters this means over-riding the normal thermostat settings and heating the stored water to a higher temperature (tempering valves are required for water heaters already, so this would not increase scalding risk, but if activated often, would fractionally reduce tank service life). For pool pumps, this would mean operating for the duration of a DRM4 event, irrespective of the user timer settings. However, run time during a DRM4 event would have to be subtracted from the scheduled run time, so there would be no increase in daily operation. For electric vehicle chargers, DRM4 is a signal to absorb more energy (provided there is a vehicle connected to the charger, and the on-board controller allows more charging). During a DRM5 event any available stored energy would be discharged to the grid (subject to over-ride by the vehicle's own controller).

AS4755 is unique in that it is the first standard of this kind published, and is already being used by some air conditioner manufacturers in Australia. There are no comparable smart appliance interface standards available anywhere else in the world at present, so there is no possibility of conflict.

Table 1. Demand Response Modes in AS4755

Electrical Products	**AS4755 part**	**Demand Response Modes (DRMs)**			
		Minimum load/off	Reduced load	Load shift/ forced on	Discharge Energy
Air conditioners	3.1 (a)	DRM 1	DRM2,3	NA	NA
Pool pump controllers	3.2 (b)	DRM 1	DRM 2	DRM 4	NA
Electric storage water heaters	3.3 (b)	DRM 1	DRM 2	DRM 4	NA
Solar-electric water heaters	3.3 (b)	DRM 1	DRM 2	DRM 4	NA
Heat pump water heaters	3.3 (b)	DRM 1	DRM 2	DRM 4	NA
Electric Vehicle Rechargers	3.4 (c)	DRM 1	DRM 2	DRM 4	DRM 5

(a) Published part. (b) Advanced draft. (c) Drafting not yet commenced, so DRMs indicative only

Activation of the Interface

The demand response capabilities of an AS4755-compliant product are only latent until the interface is activated by connection to a DRED (which provides a physical pathway) and there is a contractual agreement between the remote agent and the user. The user may agree to direct load control (DLC) of the appliance under defined conditions, in return for some agreed benefit, or the remote agent may offer a TOU tariff under which the user can choose to optimise consumption (or bear the cost penalty).

The following diagrams illustrate the range of activation pathways available. Figure 2 illustrates activation by DREDS which click on to the AS4755 interface, forming a simple home area network (HAN) that is effectively under the control of the remote agent rather than the user. The DREDs may be configured to receive control signals by whatever means the utility prefers – ripple control (popular in Australia, as a legacy of the large off-peak hot water load), mesh radio, FM radio (also used by some Australian utilities), the internet or any other means. Some local electronics companies have already designed DREDs capable of operating with both ripple control and local powerline carriers (ie Homeplug), with the mode selectable by the installer.

Figure 3 shows how a single DRED can replace separate units, with the advantage that the user can configure it on site to switch appliances in priority order during demand response events.

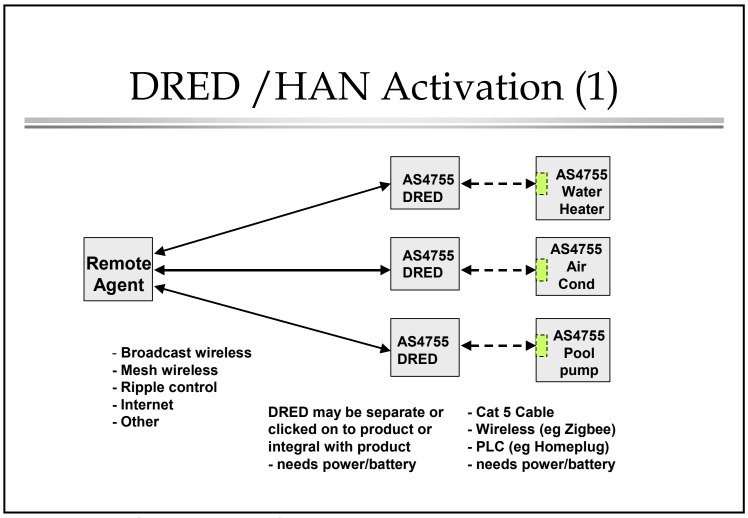


Figure 2. AS4755 Interfaces activated by separate DREDs

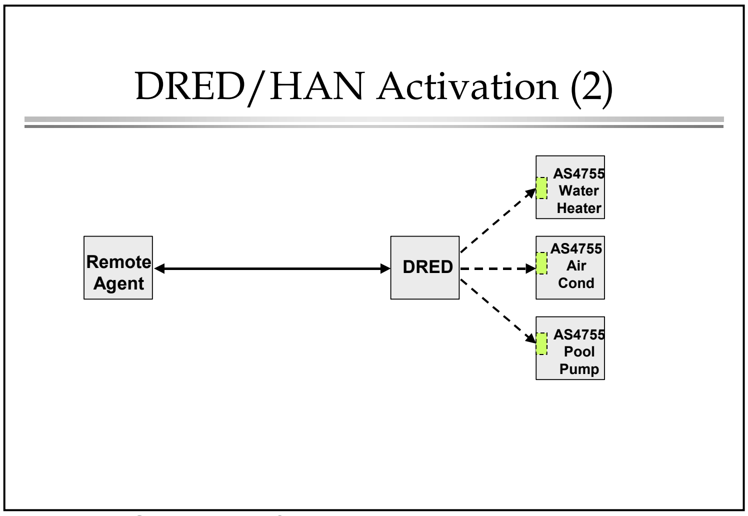


Figure 3. AS4755 interfaces activated by a single DRED

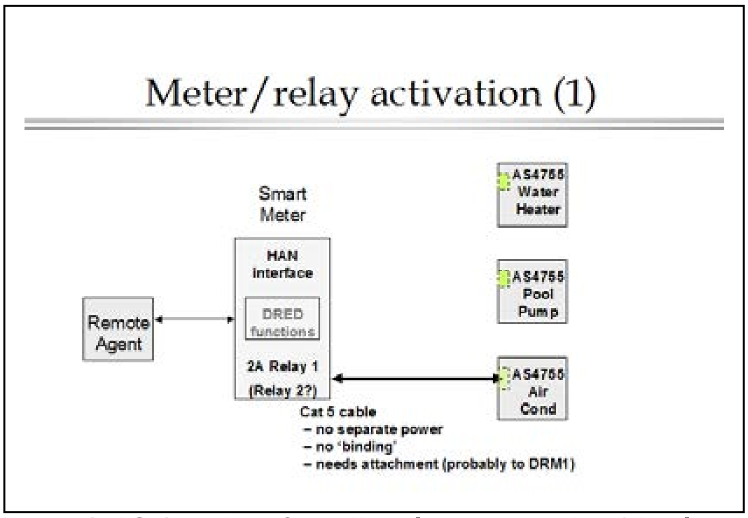


Figure 4. AS 4755 interface directly connected to 2A relay on Smart Meter by cable

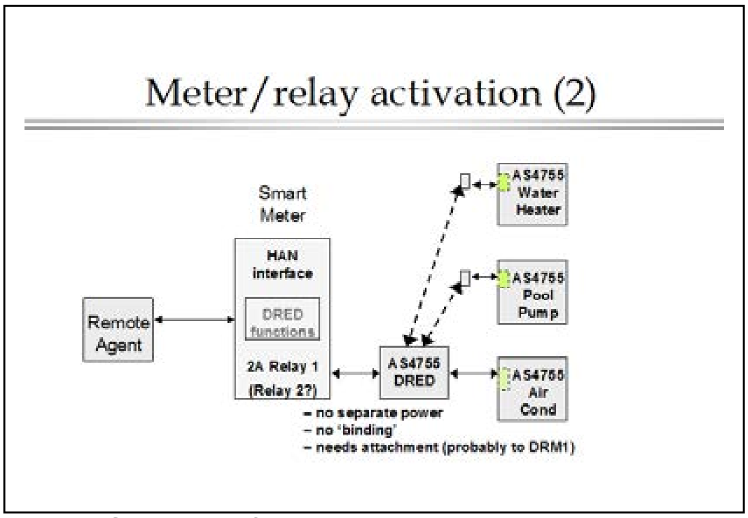


Figure 5. AS4755 interface indirectly connected to 2A relay on Smart Meter via DRED

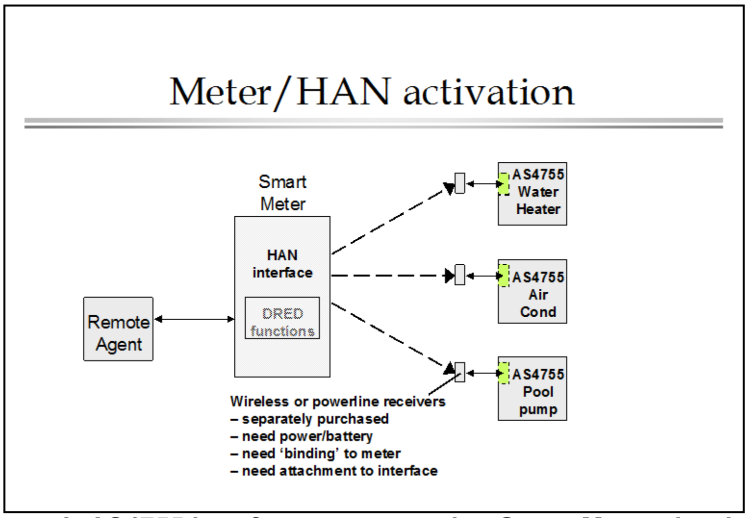


Figure 6. AS4755 interfaces connected to Smart Meter via wireless Home Area Network

The electricity meter itself can function as a DRED. In 2008, at the instigation of Australian energy Ministers, utilities, government agencies, consumer representatives and other stakeholders started work on the development of uniform technical specifications for smart metering in Australia.[11] A rollout of smart meters will have several implications for the development of smart appliances:

- Smart meters could pass on DLC instructions, and so enable customers with smart appliances to participate in and benefit from utility DLC programs without necessarily enrolling in TOU tariffs or having to purchase additional equipment to set up a HAN; and

- Smart meters could transmit continuous energy price, CO_2-intensity or other information about the grid to customers who wish to pre-set their own DREDs so that their appliances respond according to their own preferences.

Ministers directed the metering working groups to consult DCCEE and Standards Australia, to ensure that the national smart meter standards support DLC and demand response. As a result, the Smart Meter Specifications published at the end of 2010 [12] require the meter to pass through the AS4755 DRM signals in Table 1, and also provide for two means of physically linking to AS4755 interfaces:

- Via a wireless HAN likely to be based on Zigbee and/or Homeplug standards (the installing utility would decide which). This would require corresponding Zigbee or Homeplug receivers (each with its own power supply or battery) to be clicked on to the AS4755 interfaces on the appliance at the site (Figure 6); or

- Via a 2 Amp rated voltage-free relay designed for direct cable connection to the AS4755 interface. The advantage of this pathway is that it would not require a receiver with a separate power supply, and would work in circumstances where power line or wireless signals are blocked (a situation that has been found to be all too frequent in trials so far). The disadvantage is that the relay could only operate one DRM on one appliance (Figure 4), unless it was connected to a DRED which multiplexed the signal (Figure 5), so introducing further cost and complexity.

However, the limitation of the relay to a single DRM turns out to be relatively insignificant. Cost-benefit modelling shows that accessing DRM1 alone, and only on air conditioners, would deliver about 87% of the total economic benefit of summer peak load reduction (pool pumps account for the other 13% - the summer benefit from electric water heater DLC is small, but the winter benefit is greater).[12]

Flexibility and Simplicity

The great advantages of this arrangement are flexibility and simplicity. Once an AS4755-compliant smart appliance is installed, it can accommodate any sequence of pathways. The physical changes required are as simple as substituting one DRED for another, or connecting or removing a cable. This would not be done by the householder– AS4755 specifies that the interfaces should be located under secure covers designed for access by an authorised person – but the extra-low-voltage system means that the authorised person need not be a certified electrician. This lowers the cost of large scale rollouts, making it possible for high-volume pay-TV and communications cabling companies to undertake AS-4755 activation work.

The arrangements also means that any AS4755 appliance can be substituted for any other. Indeed, the utility need not know what device is actually connected. If it propagates a DRM1 signal, for example, all DREDs receiving it (that have been enabled because the user has consented to participate in the DLC program) will close the DRM1 relay, and whether that relay is connected to an air conditioner or a pool pump, it will cease operating until the DRED received a signal to open the relay. More complex DLC strategies would be possible if the utility could address individual appliances at the user's site, and address distinct DRMs on each appliance. This would require logging of the appliance type and characteristics at the time of DRED installation.

Automatic logging of appliance type and capability, and reporting of operating state to the DRED, are perhaps the only potentially useful features that this regime does not support. There is no provision for the appliance to communicate information about itself to the DRED. It is relatively simple to design a DRED to detect and report to the remote agent if there is a current flowing when a relay closes (although this would not prove that it was necessarily an appliance!) but full 2-way communications with the appliance is not possible.

The value of two-way communication down to the appliance level was discussed at length during the development of AS4755. Ultimately, the electricity utility view was that DLC programs will always be based on probability. If the program is properly designed, most appliances will respond as expected. A few users will enroll in a DLC program to gain the monetary benefit and then deliberately disconnect the DRED so that their appliances are never interrupted (of course, if they are on a TOU tariff they may find the cost of defeating the DLC signal to be high). Another group will enroll in DLC programs in good faith, but will not have their appliances interrupted due to a failure somewhere along the communications pathway. (If they are on a TOU tariff they may eventually notice that they are missing out on savings, and bring the matter to the notice of the utility themselves). Yet another group will not reduce load during a DLC event simply because they are not home at the time or do not have the relevant appliances running. They should still be rewarded for making their appliances available for DLC, and if anything further rewarded for not contributing to the peak load problem at the time!

It would be difficult, expensive and ultimately unnecessary to directly determine the status and actual load reduction achieved by every appliance in every household during every DLC event. While the remote agent obviously needs to monitor the aggregate response to demand response events, and build up confidence in predicting load reductions, data can be collected at the meter, transformer or substation or level, through well-designed statistical trials. Ultimately, if the remote agent does not get the required load reduction through calling a DLC event in one suburb, it can call on more suburbs, or else start with a DRM2 signal (reduced load operation) and then proceed to a DRM1 signal (complete interruption) if there is still a load problem.

Making AS4755 mandatory in Australia – Costs and Benefits

Australian government are currently considering a proposal that all ‘priority appliances’ (ie those in Table 1) imported or sold after a target implementation date (either October 2011 or October 2012) must comply with AS4755. It is estimated that this would increase average appliance purchase price by about AUD 10. The benefits derive from the expectation that a proportion of appliance owners would use the AS4755 capabilities, or authorise the electricity utility or other intermediary to access those capabilities, in return for some incentive. Benefits would accrue to all electricity users, including those that do not participate, via significant reductions in network costs.

Cost-benefit modelling shows that the measure would be highly cost-effective, with a potential net benefit of about AUD 13,600 million for appliances installed up to 2025, at a benefit/cost ratio of 9.3 (This compares with a projected net benefit of about AUD 32,000 million for the entire suite of mandatory appliance energy efficiency programs).[13] The projected savings are equivalent to a net present value of AUD 1,540 for every household in existence in 2010 (at a discount rate of 7%). This could support an AUD 170 reduction in electricity bills per household in every year to 2025, if returned to households as tariff reductions. Benefits for New Zealand have also been calculated.

Direct Load Control programs for priority appliances could attain nearly 5,000 MW of controllable load during the summer peak by 2025, offsetting about a third of the projected growth in summer maximum demand in the central and eastern states (the ’National Electric Market’ region, Figure 7). This is based on 50% cycling (equal periods on and off) for participating air conditioners, and 100% off-cycling for pool pumps, for not more than 30 hours per year. Nearly twice this load would be available during emergency events.

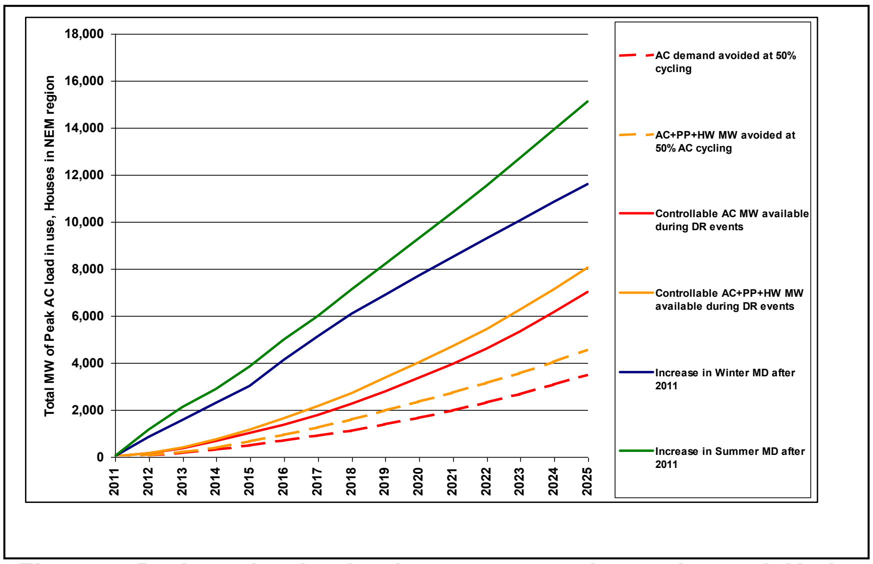


Figure 7. Projected reduction in summer maximum demand, National Electricity Market area (Excludes Western Australia and Northern Territory)

Sensitivity analysis indicates that the proposal would be highly cost-effective even under assumptions of higher costs, lower benefits and lower activation and participation rates. It would still be cost-effective if the lifetime of the measure were only 7 years. In other words, even if a global standard for appliance demand response takes effect from 2018, making AS4755 redundant (and there is no indication that this will happen), the measure would still be cost-effective as an interim strategy

While the benefits of smart appliances can be realised independently of smart metering, in-home displays and TOU pricing, there are many areas where benefits can be mutually reinforcing. One such area is the inclusion of a means for smart meters to interface directly with AS4755 appliances via a 2 Amp voltage-free relay built in to every smart meter.

The value of the proposal is primarily in the reduction of energy supply infrastructure costs, not in energy savings or emissions reductions, although the energy use permanently foregone during demand response events would lead to some minor reduction in emissions. Energy labelling and minimum energy performance standards (MEPS) would remain the most effective strategies to increase appliance energy efficiency and reduce end-use emissions, just as they are today.

The potential for greenhouse reduction on the supply side depends on the amount of renewable energy that would otherwise be wasted, the share of water heaters and pool pumps capable of energy storage/time shifting (DRM4) and thereby displacing fossil fuel-generated energy, and the number of householders making their appliances' DRM4 capability available to DLC programs. As DRM4 capability would not be mandatory, it is not possible to estimate these values at present.

There may be small energy costs for adding DR capability in some appliances, because of the need to maintain an extra-low-voltage electrical potential across the control circuits. For appliances with electronic controls (as is the case with nearly all new air conditioners and pool pump controllers), there should be no additonal standby losses from maintaining this capability. However, most electric storage, solar-electric and heat pump water heaters use mains voltage controls at present, so adding a low-voltage capability could also add a new source of standby energy loss. If so, this would be held to less than 1W, the global standby loss benchmark level endorsed by Australian governments.[2]

However, the standby use of DR devices should be outweighed by the ability to make use of renewable generation that would otherwise be wasted during high wind/low demand periods. Wind generation capacity installed in Australia at the end of 2009 totaled 1,668 MW, producing 5,000 GWh of energy annually.[14] Another 558 MW was under construction. Increasing wind utilisation from all these projects by just 1% would mean an additional 66 GWh displacement of fossil fuel generation each year, which would more than compensate for the standby losses estimated above.

Conclusions

If there were global standards for smart appliances and smart grids, and if the appliances that are priorities in Australia met those standards, there would be no need for AS4755 or for mandating AS4755. However, the Department of Climate Change and Energy Efficiency, which has closely monitored international developments in this area since 2004, through direct contact with relevant agencies, international organisations and appliance manufacturers, has formed the view that workable smart appliance standards, other than AS4755, are not likely for the foreseeable future.

It is recognised that the proposed regulatory action would places Australia (and New Zealand, if it participates) at the forefront of global regulatory action to support the development of smart appliances. On balance, this carries less risk than the failure to take regulatory action, especially as other decisions critical to the development of smart grids and smart metering in Australia will have to be taken over the coming year or two.

As long as there are competing technologies and lack of standardisation, neither appliance manufacturers nor energy utilities can risk committing to a single approach. However, if elements of the smart grid are put in place without any smart appliance strategy, there is a risk that the investments will be stranded. The AS4755 interface appears to offer a low risk option, by facilitating the development of smart appliances without precluding future developments in communications, metering or Home Area Networks.

After several years of years of considering that concerted internationall action was the best way forward on smart appliances, it now seems that only action and standardisation on a smaller scale – regional or national – can overcome the barriers to progress. However, that should not preclude global action, and Australian Government and Standards Australia are eager to work with other governments and international standards bodies towards that aim. However, Australia's growing peak demand problems and particular appliance preferences and load patterns make it urgent to implement a local solution, even as an interim one. In any case, it may be necessary to take these steps in order to stimulate the development of a global response, which otherwise may not occur.

---

[2] Australia was the first nation to publicly state that it would pursue the 'one-watt' target under the banner of the IEA standby power initiative. http://www.energyrating.gov.au/library/pubs/200914-achievements.pdf

References

[1] *Electricity Statement of Opportunities for the National Electricity Market*, Australian Energy Market Operator, 27 August 2009.

[2] George Wilkenfeld and Associates. *A National Demand Management Strategy for Small Air Conditioners: the Role of the National Appliance and Equipment Energy Efficiency Program (NAEEEP*), for the Australian Greenhouse Office, November 2004, available at http://www.energyrating.gov.au/library/details200422-ac-demandmanagement.html

[3] George Wilkenfeld and Associates, with National Institute of Economic and Industry Research, *Regulation Impact Statement: for Decision - Phasing Out Greenhouse-Intensive Water Heaters in Australian Homes*, for the National Framework for Energy Efficiency, November 2010

[4] *Smart Domestic Appliances Supporting the System Integration of Renewable energy: Smart-A*, Intelligent Energy Europe, 2009.

[5] Wilkenfeld G. *Building Demand Response Capability into Appliances: A-HELP in difficult times.* Proc. of the International Energy Efficiency in Domestic Appliances & Lighting (EEDAL) Conference 2006, London, 21-23 June.

[6] Australian Standard AS 4755.3.1-2008, *Demand response capabilities and supporting technologies for electrical products, Part 3.1: Interaction of demand response enabling devices and electrical products-Operational instructions and connections for air conditioners*. (Available for purchase from Standards Australia at: http://infostore.saiglobal.com/store/.)

[7] Wilkenfeld G. *Making demand response standard for household air conditioners: the Australian experience* Proc. of the International Energy Efficiency in Domestic Appliances & Lighting (EEDAL) Conference 2009, Berlin, 16-18 June

[8] *Smart Grid White Paper: The Home Appliance Industry's Principles & Requirements for Achieving a Widely Accepted Smart Grid,* (US) Association of Home Appliance Manufacturers (AHAM), December 2009

[9] *Assessment of Communication Standards for Smart Appliances: the Home Appliance Industry's Technical Evaluation of Communication Protocols,* (US) Association of Home Appliance Manufacturers (AHAM) October 2010

[10] *Smart Grid Standardization Roadmap*, Prepared by SMB Smart Grid Strategic Group (SG3), International Electro-technical Commission , June 2010

[11] http://share.nemmco.com.au/smartmetering/default.aspx

[12]http://share.nemmco.com.au/smartmetering/Document%20library/Work%20Stream%20documentation/BRWG/BRWG%20deliverable%2001%20-%20Smart%20Metering%20Infrastructure%20(SMI)%20Minimum%20Functionality%20Specification%20v1.1.pdf

[13] George Wilkenfeld and Associates. *Consultation Regulation Impact Statement: Mandating 'Smart Grid' interfaces for air conditioners, water heaters and other appliances,* for the Equipment Energy Efficiency (E3) Committee, December 2010

[14] http://cleanenergyaustraliareport.com.au/technologies/wind-2/

Smart Appliances: The Future of Appliance Energy Efficiency

Kevin Messner
Chellury (Ram) Sastry

Association of Home Appliance Manufacturers
Pacific Northwest National Laboratory

Abstract

Smart appliances can provide significant energy efficiencies that yield energy savings and lead to consumers saving money, but there are challenges that need to be overcome. Home appliances, especially smart appliances, are a critical component to a modern electric grid in order to manage electrical energy more efficiently and effectively.

Home appliances have made great strides over the last 20 years in improving machine efficiencies, but the traditional mindset of continually increasing machine efficiencies is leading to diminishing returns in terms of kilowatt-hours in savings. However, there are yet the untapped and plentiful efficiencies that can be achieved through an integration of smart appliances and the smart grid.

Of utmost importance is recognition that smart appliances provide energy savings. By shifting residential load from peak times of day to when there is less demand for electricity, the entire power system is less costly and operates more efficiently. For example, in order to match supply and demand at all times, power system operators maintain what are referred to as "spinning reserves" that are invoked in the event of a contingency. These reserves are a necessary, but wasteful and expensive, component of the current electrical grid to maintain real time matching of supply and demand. Instead of generators supplying spinning reserves, electrical loads such as smart appliances can be used to quickly, actually instantaneously, adjust demand to match supply – a new way of thinking, a lower cost option, and a more environmentally friendly path to the future.

There are challenges that need to be overcome to make a smart grid a reality. One such critical challenge is consumer use and acceptance of smart appliances.

Introduction

Smart appliances can provide significant energy efficiencies that yield energy savings and lead to consumers saving money, but there are challenges that need to be overcome. Home appliances, especially smart appliances, are a critical component to a modern electric grid to manage electrical energy more efficiently and effectively.

Home appliances have made great strides over the last 20 years in improving machine efficiencies. Clothes washers use 70 percent less energy and refrigerators use half the energy. Today's average refrigerator uses less energy than a 60 watt light bulb. Another 10 percent improvement in refrigerator machine efficiency would achieve less than a 6 watt savings in power, but envision a smart refrigerator that can shift 500 watts of defrost power to periods when electrical demand is low or renewable energy is plentiful. Instead of continuing down the worn out path of ever increasing appliance efficiencies, it is required to change focus to new areas with greater potential. The traditional mindset of continually increasing machine efficiencies is leading to diminishing returns in terms of kilowatt-hours in savings, as opposed to the yet untapped and plentiful efficiencies that can be achieved through an integration of smart appliances and the smart grid.

Of utmost importance is recognition that smart appliances provide energy savings (both machine and grid system savings). By shifting residential load from peak times of day to when there is less demand for electricity, the entire system is less costly and works more efficiently because of less congestion in the transmission lines and distribution system. The regional generation mix of base-load, intermediate-load, and peak-load generation type certainly influences the use of demand response capability, but these inherent inefficiencies in the current system lead to the need for "spinning reserves," which can be idling power plants needed to protect the system reliability. These reserves are a necessary, but wasteful and expensive, component of the current electrical grid to maintain real time matching of supply and demand. It is such an important part of the electrical grid that spinning reserves have their own market and pricing structure.

Traditionally, the need to match supply and demand of electricity has always been met by adjusting supply (generation), i.e., invoking reserves that are set aside to compensate for any imbalance between supply and demand. But adjusting demand instead of supply can be instantaneous and clean. Electrical loads from smart appliances can be used to quickly, in some cases instantaneously, adjust demand to match supply – a new way of thinking, a lower cost option, and a more environmentally friendly path to the future.

There are challenges that need to be overcome to make a smart grid a reality. For example, consumer use and acceptance of smart appliances is critical. For this to occur, the consumer must have complete control of his or her appliance. However, the appliance needs to adjust its operations automatically so that lifestyle and behavioral changes are minimized, and electricity must be priced dynamically throughout the day so that the consumer can save money on his or her electricity bill by allowing reminders and unobtrusive operational changes to be made automatically. The appliance should use a "set it and forget it" type of model for the smart grid capabilities so that consumers will not have to continually monitor price signals and monitor their behavior continuously.

Smart appliances provide a significant contribution to energy efficiency and the development of a smart grid, which will improve efficiencies, increase the use of renewable energy, reduce costs, and increase reliability. However, there need to be incentives to manufacturers to sell smart appliances to hasten the development of an effective smart grid.

The Problem: Electricity Use Is Increasing

The U.S. Energy Information Administration (EIA) projects that world net electricity generation will increase by 87 percent, from 18.8 trillion kilowatthours in 2007 to 25.0 trillion kilowatthours in 2020 and 35.2 trillion kilowatthours in 2035. And for world residential energy use the projection is an increase of 1.1 percent per year, from 50 quadrillion Btu in 2007 to 69 quadrillion Btu in 2035, or a 38 percent increase in electricity use by 2035.[i]

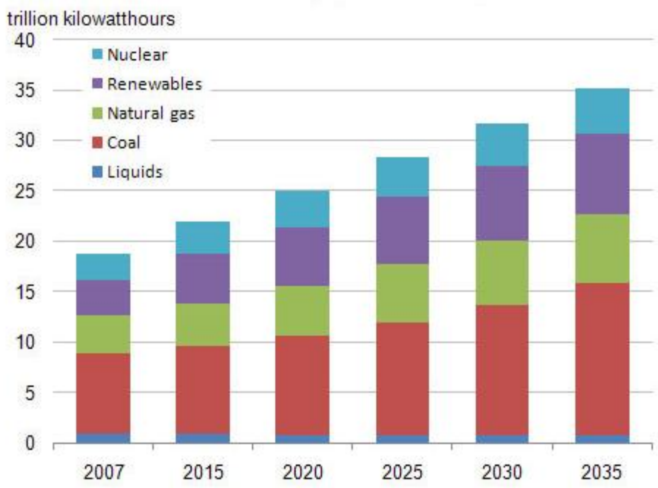


Figure 1: World Electricity by Fuel (Source: EIA 2010 International Outlook)

Peak demand increases may be even more pronounced. One industry forecast of peak demand, which extrapolates the North American Electric Reliability Corporation's 2005 Peak Demand and Energy Projection Bandwidths, predicts non-coincident peak demand that is 55 percent higher in 2030 than it was expected to be in 2008.[ii] Summer peak load was expected to increase 430 GW in 2030 from the existing 781 GW. This forecast does not include expected demand response programs, but does include modest forecasted efficiency savings. Peak demand is the most costly because 10 percent of the generation and 25 percent of the transmission infrastructure are needed to service only

400 hours per year (see Figure 2). However, the EIA 2010 Annual Energy Outlook projects that the U.S. electric power sector generating capacity will grow by only 8 percent from 2010 to 2030.

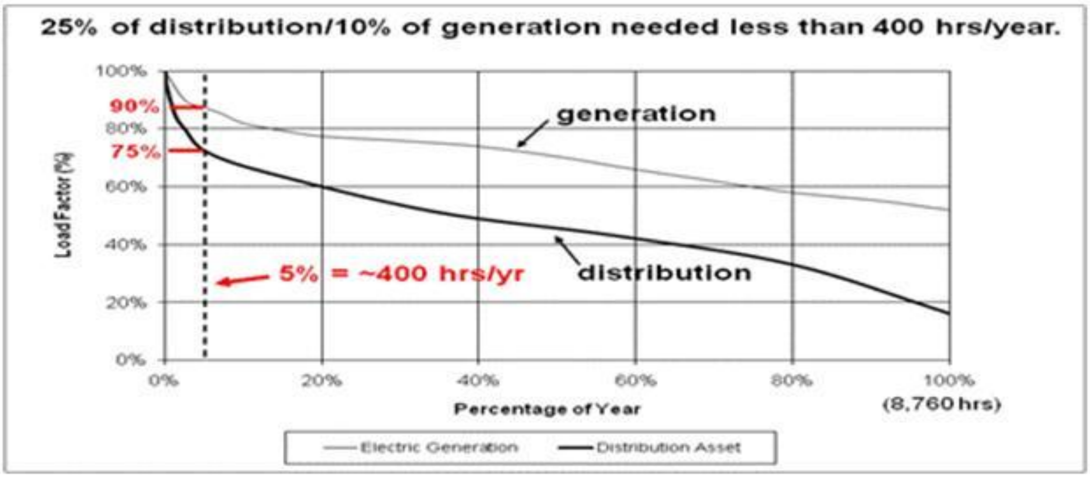


Figure 2: Distribution/Generation Needs (Source: Pacific Northwest National Laboratory)

The Smart Grid Is Critical in Addressing the Increase in Electricity Use

As discussed below, the smart grid is an important part of efforts to address projected increases in electricity use. The Electric Power Research Institute (EPRI) estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030.[iii] And the residential sector is critically important to managing the electrical grid into the future. The residential sector represents 37 percent of electricity use in the U.S. and is the largest consuming sector of electricity (see Figure 3).

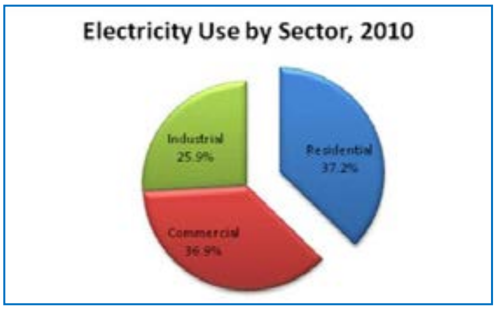


Figure 3 (Source: EIA Annual Energy Outlook)

Demand response, augmented by the smart grid and smart appliances, will result in some energy savings and reductions in costs. The North American Energy Standards Board (NAESB) has defined demand response as "changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentives designed to induce lower electricity use at times of potential peak load, high cost periods, or when systems reliability is jeopardized."[iv] In other words, when an electric utility company or third party energy service provider encounters a problem, it can send a signal alerting the consumer of the complication so that the consumer can react by reducing load during this critical time period. Reduction in energy usage during critical periods is the result of a response to a request for lowered energy usage. Critical time reductions of energy use can be accomplished by either "shifting" usage to a non-critical time of the day or by "shedding" load to reduce peak power.

According to EPRI ". . . load reductions offered by demand response and load control programs facilitated by a Smart Grid can yield energy savings and reductions in carbon emissions."[v] And U.S. Department of Energy Secretary Chu has recognized that "[s]mart grid technologies will give consumers choice and promote energy savings, increase energy efficiency, and foster the growth of renewable energy resources."[vi] Further evidence that reducing peak power is linked to saving energy is the EIA's Electric Power Annual 2008 at Table 9.2 in which utilities reported for every 1kW of peak load reduction there is a corresponding 139 kWh of energy saved.

Reducing peak load provides several other benefits:

- provides relief during capacity-constrained periods
- reduces transmission congestion
- minimizes operation of peaking plants
- defers the need for new generation

According to a report released by U.S. Vice President Biden on August 24, 2010:

> *Smart Grid technology, combined with supportive policy, allows for smarter use of energy, largely by increasing the transparency, measurement, and control of energy used by the players who supply, transmit, distribute, and demand it. Through automated sensors and controls as well as dynamic pricing, this intelligent infrastructure will make the electric system more reliable, empower consumers and utilities to use energy more wisely, help manage peak demand, enable larger scale use of renewable energy and electric vehicles, and reduce U.S. dependence on oil.*[vii]

Reportedly in Europe, the smart grid could save €52 billion.[viii] The sizeable savings would arise from reducing losses in the electricity distribution network through automation and encouraging consumers to cut energy consumption with smart meters that provide more accurate and timely information, according to experts from the Smart Energy Demand Coalition in Brussels.

Smart Appliances Used as Spinning Reserves

To balance supply and demand continuously despite sudden, unexpected failures of generators and/or transmission lines, utilities typically maintain contingency reserves to compensate for such failures. Contingency reserves include: 10-minute spinning reserves, 10-minute non-synchronized reserves, and 30-minute operating reserves. The 10-minute spinning reserves are typically provided by base-load generators operating below their rated capacity and then ramping them up when called upon to deliver spinning reserves. Despite their importance to power system operation, the larger the spinning reserve requirement, the greater the emissions. This is a wasteful, but necessary, part of the current U.S. electrical grid.

Reserves are a significant cost to the system which is passed down to the consumer. Figure 4 shows the reserve margins around the U.S.[ix] Regional rules differ but typically, sufficient reserves in the form of capacity must be set aside to be invoked in the event of the largest credible contingency, which could be the loss of a generator or a transmission line. Such reserves are referred to as contingency reserves. Typically, half of the contingency reserves have to be spinning, i.e., available in 10 minutes. As an example, in the Electric Reliability Council of Texas (ERCOT), which operates the electric grid and manages the deregulated market for 85 percent of the state's load, typically has to maintain 2,500 MW of spinning reserves in case both nuclear generators go down. This represents 5-7 percent of the total load in the area.

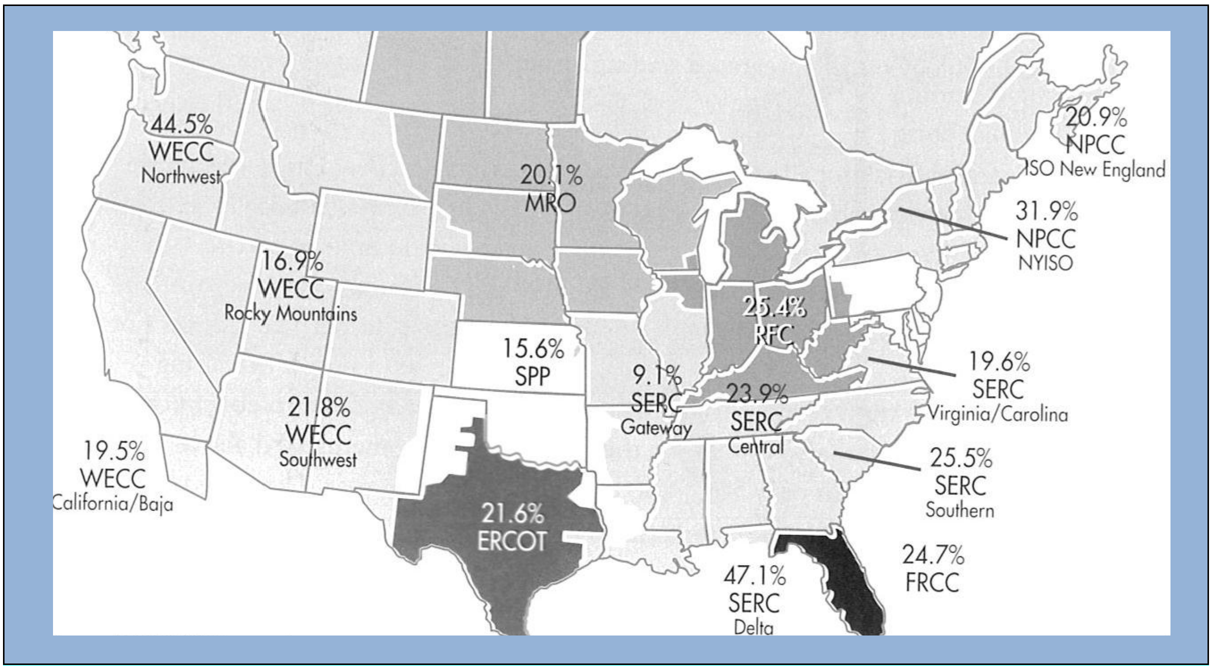


Figure 4: Summer 2009 Reserve Margins By Region (Source: NERC 2009 Summer Assessment)

Fortunately, there is another way -- a cheaper, cleaner, more efficient way -- of handling spinning reserve requirements. It can come from load (demand) instead of generation (supply). If it comes from load it is "green" because it avoids additional generation and unused "idling" generation. In recent years, there has been considerable interest in exploiting the enormous potential of demand response towards providing spinning reserves.[x] This is over and beyond peak-load reduction. Residential loads capable of interacting with the grid (smart appliances) such as refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers are particularly suited as sources of 10-minute spinning reserves because the operation of such loads can be interrupted for short periods without causing any diminution of the quality of service for consumers. Furthermore, end-use load can often be curtailed almost instantaneously as opposed to generators that must ramp up and down subject to operating constraints in order to avoid equipment damage. Finally, given the potentially large number of responsive end-use loads, their aggregate response could be extremely reliable when called upon to provide spinning reserves. Thus, residential loads could obviate the need for maintaining some fossil-fuel based generation for providing spinning reserves thereby reducing operating costs and also lowering emissions.

Consumers will save money when smart appliances are used for spinning reserves. One recent study sponsored by PJM[xi] and the Mid-Atlantic Distributed Resources Initiative estimates that a three percent load reduction during peak could reduce electricity prices by up to 12 percent. This price reduction corresponds to approximately $330 million in savings per year, of which $20 million is estimated to be saved by the demand-reducing customers. Two to three times that amount would be saved by other customers in the Mid-Atlantic States due to lower market prices, and $8-12 million would be saved by customers outside the region.

Benefits of Smart Appliances

The Pacific Northwest National Laboratory (PNNL), which is a U.S. Department of Energy (DOE) laboratory, undertook an in-depth analysis to evaluate the precise benefits of smart appliances (refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers) towards providing both peak-load reduction and spinning reserves through demand response.[xii] In this report, PNNL presents the results of an analytical cost/benefit study of residential smart appliances from a utility/grid perspective. This study was prepared as an independent technical analysis of a joint stakeholder[xiii] petition to the ENERGY STAR program within the Environmental Protection Agency (EPA) and DOE. The goal of the petition is, in part, to provide appliance manufacturers incentives to hasten the production of smart appliances and jump start the development of the smart grid. The underlying hypothesis is that smart appliances can play a critical role in addressing some of the societal challenges, such as anthropogenic global warming, associated with increased electricity demand, and facilitate increased penetration of renewable sources of power.

The PNNL analysis found that the benefits derived from a smart appliance are more than equivalent to a corresponding five percent change in operational machine efficiencies. It is expected that given sufficient incentives, value propositions, and suitable automation capabilities built into smart appliances, residential consumers will adopt these smart appliances and more effectively manage their home electricity consumption.

The analytical model used in the cost/benefit analysis consists of a set of user-definable assumptions such as the definition of "on-peak" (hours of day, days of week, months of year), the expected percentage of normal consumer electricity consumption (also referred to as appliance loads) that can be shifted from peak hours to off-peak hours, the average power rating of each appliance, etc. Based on these assumptions, the wholesale grid operating-cost savings, or "benefits," that would be realized if the "smart" capabilities of appliances were invoked was estimated. The benefits considered were peak-load shifting for some percentage of appliance loads and ancillary services provided by responsive appliance loads. Specifically, responsive or dispatchable smart appliance loads that meet power system needs for spinning reserves that would otherwise have to be provided by generators were considered. The rationale for this is that appliance loads can be curtailed for about ten minutes or less in response to a grid contingency without any reduction in the quality of service to the consumer.

A summary of the results is provided in Table 1 and Table 2. It shows that in virtually all the markets, in either optimistic or pessimistic assumption scenarios, the benefit-to-cost ratio for the addition of smart grid capabilities in appliances exceeds a corresponding change of 5 percent in traditional machine efficiencies, and in some cases by more than tenfold.

Table 1: Benefit-to-Cost Ratios of Smart Appliances Based on "Optimistic" Assumptions

	DW	CW	RAC	Freezer	Refrigerator	Dryer
PJM 2006	528%	563%	733%	539%	536%	680%
ERCOT 2008	817%	871%	1060%	881%	877%	1054%
NYISO 2008	367%	403%	585%	357%	355%	462%
NYISO 2006	353%	389%	712%	346%	344%	442%
CAISO 2008	319%	356%	554%	313%	312%	396%

Table 2: Benefit-to-Cost Ratios of Smart Appliances Based on "Pessimistic" Assumptions

	DW	CW	RAC	Freezer	Refrigerator	Dryer
PJM 2006	136%	134%	131%	150%	150%	207%
ERCOT 2008	203%	200%	295%	230%	228%	337%
NYISO 2008	107%	106%	139%	112%	111%	147%
NYISO 2006	112%	112%	160%	119%	118%	160%
CAISO 2008	99%	100%	135%	102%	101%	134%

Another important finding of the PNNL study is that the benefits are spread across peak-load shifting, spinning reserve, and feedback effect. Tables 3 through 8 show this spread for the optimistic scenario.

Table 3: Percentage of Total Smart Refrigerator Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	8%	70%	22%
ERCOT 2008	9%	78%	14%
NYISO 2008	11%	56%	34%
NYISO 2006	11%	54%	35%
CAISO 2008	12%	49%	39%

Table 4: Percentage of Total Smart Freezer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	8%	70%	22%
ERCOT 2008	9%	77%	14%
NYISO 2008	11%	55%	34%
NYISO 2006	12%	53%	35%
CAISO 2008	13%	49%	38%

Table 5: Percentage of Total Smart Room Air Conditioner Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	63%	20%	16%
ERCOT 2008	41%	48%	11%
NYISO 2008	55%	25%	21%
NYISO 2006	65%	18%	17%
CAISO 2008	63%	15%	22%

Table 6: Percentage of Total Smart Clothes Washer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	31%	47%	21%
ERCOT 2008	37%	49%	14%
NYISO 2008	40%	30%	30%
NYISO 2006	42%	27%	31%
CAISO 2008	46%	20%	34%

Table 7: Percentage of Total Smart Clothes Dryer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	28%	55%	18%
ERCOT 2008	33%	56%	11%
NYISO 2008	37%	37%	26%
NYISO 2006	40%	33%	27%
CAISO 2008	44%	25%	30%

Table 8: Percentage of Total Smart Dishwasher Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	26%	52%	23%
ERCOT 2008	31%	54%	15%
NYISO 2008	33%	34%	33%
NYISO 2006	35%	31%	34%
CAISO 2008	39%	23%	38%

Demand Response vs. Energy Efficiency

Increasing machine energy efficiency is not the only way to drive energy savings. Demand response can also yield some energy savings. For example, cycling the dryer heating coil off while continuing to spin clothes allows use of the residual heat in the dryer, reducing heater-on time when the heater coil is restarted and yielding less total cycle energy use, but this also increases cycle time, which consumers are not enthusiastic about doing all the time. The residential consumer and smart appliances are important to the success of demand response. Since late 2007 and after passage of a U.S. energy law in 2007, for example, efficiency savings were estimated by the Electric Power Research Institute (EPRI), including savings from refrigerators, dryers, room air conditioners, clothes washers, and dishwashers. EPRI found that the savings from these appliances were a small percentage of maximum achievable potential in 2030 in relation to other residential, commercial, and industrial uses.[xiv] As appliance efficiency continues to increase, remaining opportunities for appliance efficiency savings will decline. Further information from the EPRI study is shown in Figure 5, which depicts that the maximum potential for efficiency savings in home appliances (highlighted in chart) is quite low compared with other products. In addition, in a Whitepaper released this month (May 2011) by the Institute for Electric Efficiency found that “For utility programs, changes in efficient standards and building codes may make it increasingly challenging to achieve energy savings through traditional energy efficiency programs, particularly those that target individual appliances and equipment.”[xv]

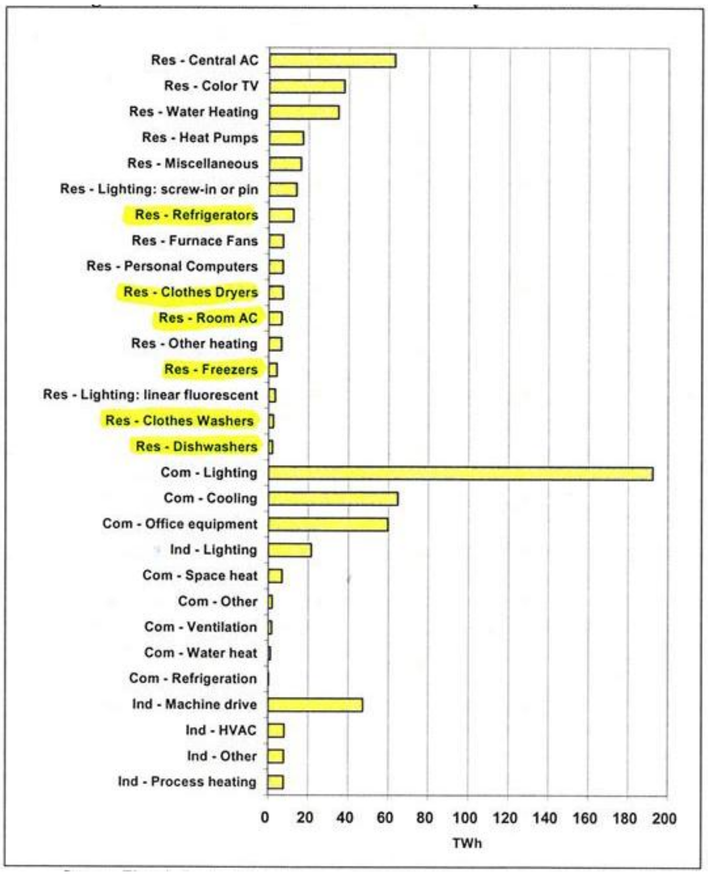


Figure 5: Maximum Achievable Potential by End Use in 2030
(Source: Electric Power Research Institute)

According to the EPRI assessment of achievable potential for energy efficiency and demand response in the U.S., demand response combined with increases in energy efficiency can offset 40 percent (173 GW) of the growth in summer peak demand by 2030 (see Figure 6).[xvi]

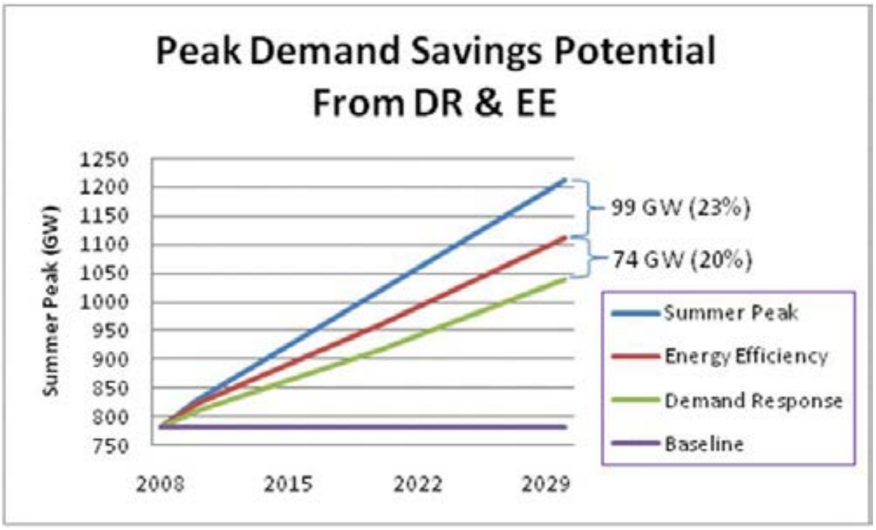


Figure 6: (Source: Rohmund, Ingrid, et. al, Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US (2010-2030).)

Significantly, residential customers offer as much demand response potential as small, medium, and large businesses combined (see Figure 7).

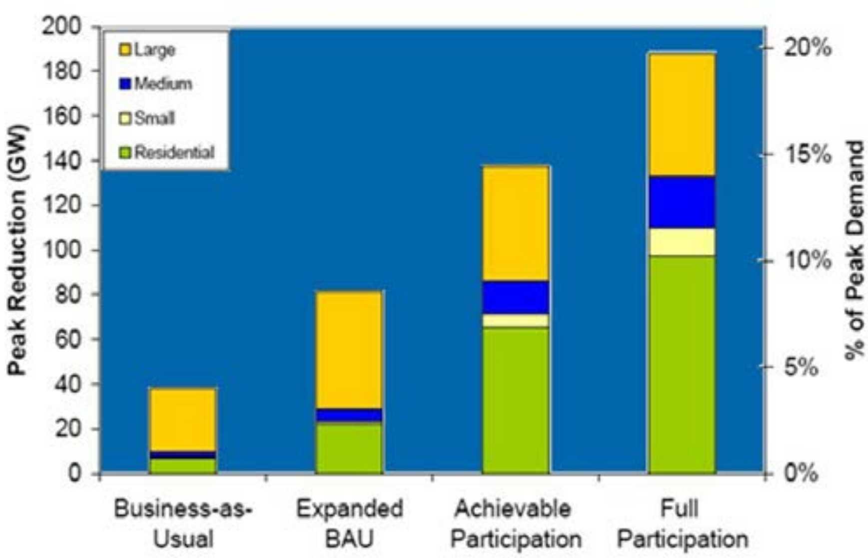


Figure 7: (Source: Federal Energy Regulatory Commission)

According to FERC, ". . . it is the residential class that represents most [sic] untapped potential for demand response. . . While residential customers provide only roughly 17 percent of today's demand response potential, in the AP [Achievable Participation] scenario they provide over 45 percent of the potential impacts."[xvii] The FERC National Assessment of Demand Response, June 2009, found that "pricing w/tech" (including smart appliances) offers more than half of the potential for peak demand reduction (see Figure 8). Furthermore, as the PNNL study indicates, further gains are possible through the utilization of smart appliances for providing spinning reserves.

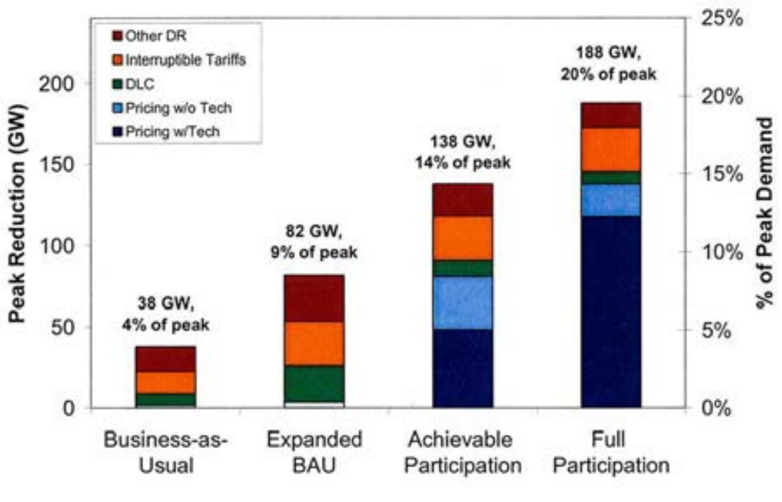


Figure 8: (Source: FERC National Assessment of Demand Response, June 2009)

Demand Reduction Yields Further Capacity Savings

Reducing demand also yields capacity savings. Reducing demand may have a 24 percent higher impact at the generating facility, which equates to even more capacity savings (see Figure 9).

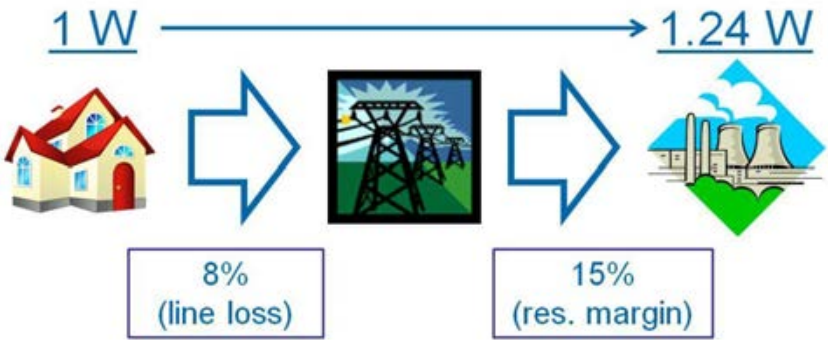


Figure 9: (Source: The Brattle Group, Power of 5%)

Transmission losses account for approximately two to four percent of the total electricity generated in the United States.[xviii] While the percentages may appear relatively low, the total amount of energy involved is considerable. The percentages equate to about 83 million MWh to 166 million MWh lost each year based on a total U.S. annual generation of 4,157 million MWh.[xix]

Increased Use of Renewable Energy

The benefit of the smart grid goes beyond energy savings. Due to environmental concerns, there has been increasing interest in recent years towards incorporating large amounts of renewable sources of energy such as solar and wind, and diminish the reliance on fossil-fuels to create a more diversified energy supply portfolio. For example, DOE has initiated a collaborative effort to explore the possibility of wind power supplying 20 percent of U.S. electricity needs by the year 2030.[xx] One of the key challenges involved with solar and wind as sources of energy is that they are intermittent and cannot be relied upon with certainty. Solar energy output can drop very quickly with passing clouds, while wind energy output changes very frequently, almost every hour. As a result, in order to balance supply and demand, a key objective of power system operation alluded to above is that energy reserves are required to be maintained based on conventional generation sources like natural gas. But doing so works against the very purpose of incorporating solar and wind energy, namely, decreasing reliance on fossil fuels. Fortunately, demand response through smart appliances can be invoked to curtail and/or defer demand for power during periods when solar and wind energy are in short supply, and to shift the demand to when there is an abundance, enabling greater utilization of renewable energy.

Thus, smart appliances and smart grid can play an important role in facilitating greater utilization of intermittently available renewable resources such as solar and wind, from which will accrue reductions in CO_2 emissions.[xxi] The intermittent nature of the renewables is a critical impediment to their greater impact. By developing a truly smart grid that can shift demand to when supply is available, this impediment gets reduced significantly. A dynamic response system like that envisioned for residential usage of smart appliances will enable renewable energy to become a more significant part of the total energy picture.

Smart Appliances Will Also Help Reduce Carbon Emissions

PNNL published a study that estimates the role of smart grid towards reducing carbon emissions.[xxii] In particular, the study evaluated the carbon reductions through nine smart grid mechanisms. PNNL found that carbon emissions can be reduced directly through smart grid applications, and indirectly by investing the operational savings resulting from smart grid into renewable sources of power generation and efficiency programs. The table below (see Figure 8) summarizes the study's findings including the key conclusion: smart grid may facilitate a 12 percent direct carbon reduction, and a 6 percent indirect reduction.

Mechanism	Electric Sector Energy CO_2 Reductions	
	Direct	Indirect
Conservation Effect of Consumer Information and Feedback Systems	3%	-
Joint Marketing of Efficiency and Demand Response Programs	-	0%
Diagnostics in Residential and Small/Medium Commercial Buildings	3%	-
Measurement and Verification for Efficiency Programs	1%	0.5%
Shifting Load to More Efficient Generation	< 0.1%	-
Support Additional Electric Vehicles (EVs) / Plug-In Hybrid Electric Vehicles (PHEVs)	3%	-
Conservation Voltage Reduction and Advanced Voltage Control	2%	-
Support Penetration of Solar Generation (RPS > 25%)	(1)	(2)
Support Penetration of Wind Generation (25% RPS)	< 0.1%	5%
Total, Share of U.S. Electric Sector Energy and CO_2 Emissions	**12%**	**6%**

Figure 10: Nine Smart Grid Based Carbon Reducing Mechanisms (Source: PNNL, The Smart Grid: An Estimation of the Energy and CO2 Benefits)

The PNNL study does not explicitly identify the role of smart appliances in carbon reductions, but smart appliances could play a role in several of the carbon reducing mechanisms in the above table.

Smart Appliances Will Help Consumers Save Money

Smart appliances will also benefit the consumer. The development of smart grid tools for consumers will enable both utilities and consumers to use electricity more efficiently, thereby reducing their costs.[xxiii] For example, dynamic pricing of electricity creates the conditions that encourage consumers to change their or the appliances' behavior by using appliances when the rates are lower, which if properly developed to minimize the need for behavioral changes by the consumer, will save consumers money on their total electricity bill. According to FERC's Assessment of Demand Response and Advanced Metering Report, there were an estimated 7.95 million installed advanced meters nationwide in 2009. These smart meters are already helping to reduce energy costs for families and businesses.[xxiv] As stated above, EPRI estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030, which would mean an electric bill savings of $20.4 billion for consumers and businesses around the country each year.[xxv]

Conclusion

We must be mindful of the current problems with an electrical system in the U.S. that is based on 100 year old technology in some parts. Electricity is being used in the home to power many other hi-tech products. Today, low frequency of blackouts is due to several reasons, such as spinning reserves and the improved technologies of the grid's control center operations, both distribution & transmission, its monitoring systems. Nevertheless, the dichotomy of 21st Century products, such as computers and iPhone, being powered by some technologies developed during the "horse and buggy" era highlights the need to modernize our electrical grid.

As this paper outlines, electricity use is increasing and peak power, which is the most expensive power, is increasing more quickly. It is time to trim some of the waste in the current system by developing an effective smart grid. In order to do this, each part of a very complex grid cannot sit and wait for other parts to go first, or even worse, wait until all the parts are completed together. If this occurs the reality of an effective smart grid in the near future does not look bright.

We can move this forward by recognizing and incentivizing the manufacture and deployment of smart appliances in the home. Home appliance manufacturers are enthusiastic about the contribution their products can make to jump starting the development of the smart grid. But appliance manufacturers cannot do this alone. No one can. In the manufacturing engineering world, there is a saying that there is a time to stop designing and start manufacturing. We are pleased with the huge progress that has been made just in the last year in resolving some of the "design issues" with the smart grid, but appliance manufacturers are ready to start manufacturing and make the smart grid a reality.

Endnotes

[i] U.S. Energy Information Administration, "2010 International Outlook," available at www.eia.doe.gov/oiaf/ieo/index.htmlk.

[ii] Ingrid Rohmund and Greg Wikler (Global Energy Partners, LLC), Ahmad Faruqui (The Brattle Group), Omar Siddiqui (Electric Power Research Institute) and Rick Tempchin (Edison Electric Institute), *Assessment of Achievable Potential for Energy Efficiency and Demand Response in the U.S. (2010 – 2030)*, Paper prepared for 2008 ACEEE Summer Study on Energy Efficiency in Buildings, p. 5-264.

[iii] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010)," ***available at*** www.energy.gov/news/9433.htm.

[iv] Recommendation to NAESB Executive Committee (July 29, 2009), "Measurement & Verification for Demand Response Programs."

[v] Electric Power Research Institute, "The Green Grid," June 2008

[vi] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide" (August 31, 2010), ***available at*** www.energy.gov/news/9433.htm.

[vii] Executive Office of the President of the United States and Vice President of the United States, "The Recovery Act: Transforming The American Economy Through Innovation," at 37 (August 2010), available at www.whitehouse.gov/sites/default/files/uploads/Recovery_Act_Innovation.pdf (emphasis added).

[viii] Available at http://www.euractiv.com/en/energy-efficiency/smart-grids-could-save-europe-52bn-news-499738, November 2010

[ix] Reserve margins are the extra supply that is available. It is calculated as the total supply capacity minus the peak demand, divided by the peak demand.

[x] B. J. Kirby, Oak Ridge National Laboratory, "Spinning Reserve From Responsive Load" (March 2003), available at certs.lbl.gov/pdf/spinning-reserves.pdf

[xi] Quantifying Demand Response Benefits In PJM: http://pjm.com/documents/media/reports/brattle-report-quantifying-demand-response-benefits-pjm.ashx

[xii] Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves

[xiii] Stakeholders include Association of Home Appliance Manufacturers, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Consumer Federation of America, and others.

[xiv] Rohmund, Ingrid, et. al. (Global Energy Partners, Brattle Group, EPRI, EEI), "Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US" (2010-2030).

[xv] Institute for Electric Efficiency, "Assessment of Electricity Savings in the U.S. Achievable through New Appliance/Equipment Efficiency Standards and Building Efficiency Codes (2010-2025) (May 2011).

[xvi] Rohmund, Ingrid ,et. al (Global Energy Partners, Brattle Group, EPRI, EEI), "Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US" (2010-2030).

[xvii] Federal Energy Regulatory Commission, "National Assessment of Demand Response" (June 2009).

[xviii] U.S. Energy Information Administration, "Electric Power Industry 2007: Year in Review" (report released January 21, 2009).
[xix] K. Forsten, Electric Power Research Institute, "Transmission Efficiency Initiative" (October 2009).

[xx] U.S. Department of Energy, available at www1.eere.energy.gov/windandhydro/wind_2030.html.

[xxi] Electric Power Research Institute, "The Green Grid" (June 2008).
[xxii]Pacific Northwest National Laboratory presentation to the U.S. Environmental Protection Agency, "Smart Grid: An Estimation of the Energy and CO2 Benefits," available at http://www.epa.gov/statelocalclimate/documents/pdf/pratt_presentation_3-23-2010.pdf.

[xxiii] Executive Office of the President of the United States and Vice President of the United States, "The Recovery Act: Transforming The American Economy Through Innovation," at 40 (August 2010), available at www.whitehouse.gov/sites/default/files/uploads/Recovery_Act_Innovation.pdf.

[xxiv] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide" (August 31, 2010), ***available at*** www.energy.gov/news/9433.htm.

[xxv] *Ibid.*

Integrating Demand Response Capability into Smart Appliances: Design and Evaluation of Distributed Scheduling

Alessandro Parisi [a], Ken Christensen [b]

[a] DIEI (Dipartimento di Ingegneria Elettronica e dell'Informazione), Universiy of Perugia, Italy

[b] Department of Computer Science and Engineering, University of South Florida, USA

Abstract

The need for a constant balance between power demand and supply, together with the lack of cost-effective solutions for storing electric energy, affects the efficiency of power grids and limits the integration of renewable sources. Dynamic pricing and demand response programs provide mechanisms to regulate the power demand according to supply conditions. We focus on designing an autonomous scheduler for appliances and electric vehicle charging stations. The proposed system enables the integration of automatic demand side management functionalities. This paper presents the system architecture, the required communication services, the scheduling problem, our scheduling algorithm, and a simulation-based performance evaluation. We believe that combining dynamic pricing and peak capping represents a viable solution to effectively achieve peak shift and manage real-time events such as forced outages. Our scheduler is based on a distributed collaborative architecture. It processes appliance tasks characterized by a deadline and a load profile. We propose an offline heuristic method that first reorders and then allocates all tasks by using alternative scheduling heuristics. We compared our offline algorithm with a brute force online cost minimization algorithm and an optimal greedy scheduler. Experimental results show how performance varies with workload and how the rescheduling mechanism significantly increases the number of schedulable tasks.

Introduction

Electric power must be consumed in the moment it is produced. Dealing with this constraint is critical for energy service providers and grid operators, whose primary objective is avoiding shortages in electricity generation. Since electricity demand fluctuates and cost-effective solutions for buffering electric energy are not available, generation systems normally employ operating reserves to ensure power grid reliability during peak consumption hours. The generation capacity is thus under-utilized and the overall power system efficiency drops. Another consequence of this scenario is the limited percentage of renewable sources that can be integrated into the grid, due to their intermittent nature. Peak consumption thus affects the efficiency of power systems and the environmental impact of energy production.

Having the ability to manage the electricity demand, in order to shift loads to off-peak hours, could mitigate the problems related to the balance of demand and supply of electricity. In this context, demand response (DR) programs provide mechanisms to regulate the power demand through curtailment signals according to conditions of the supply side, whereas dynamic pricing tariffs offer retail energy prices that vary by following the wholesale cost of electricity. According to a 2008 study by Capgemini, DR programs could achieve 25-50% of the EU's 2020 targets concerning greenhouse gas emission reduction and energy efficiency improvement [1].

We believe that power use in residential buildings can be scheduled by local controllers relying on a distributed communication protocol to achieve peak shift and to react to the state of the power grid. To this aim, we propose a smart device scheduler (SDS) that controls the operation of smart appliances and electric vehicle (EV) charging stations, based on energy service provider signals.

We highlight the importance of considering methods to manage the electric consumption for residential buildings. In 2007, the residential sector accounted for the 37.0% of the total electricity consumed in U.S. [2] and for the 28.2% of that consumed in EU-27 [3]. A 2008 Smart-A project study also shows how, in a typical European house, a washing machine, a tumble dryer, and a dishwasher together account for a significant average consumption of 597 kWh per year and how those appliances can be shifted up to 9 hours [4]. Also, the growth of the EV market may have a major impact on power systems. This concern is demonstrated by the efforts of the EDISON project that addresses the integration of charging systems into the future smart grid through a vehicle-to-grid framework [5].

In the actual electricity market, it is crucial to regulate the demand according to the marginal costs of production [6]. In an ideal scenario where the demand follows price variation with enough elasticity, dynamic pricing strategies are sufficient to achieve that goal. Unfortunately, electricity consumers are not accustomed to dealing with varying prices, so their responsiveness is low. Regarding this, Braithwait states that the “responsiveness depends on price levels, customer types, and the degree of technology assistance provided” [7]. Also, Nordman suggests that the adoption of dynamic pricing is necessary but not sufficient to guarantee the needed level of dynamism for load consumption adjustment [8]. The idea behind our SDS is to improve the level of responsiveness by using peak cap signals together with a dynamic pricing tariff. By peak cap we intend a DR program wherein users accept terms under which a fine will incur if their consumption exceeds the established cap in a given time frame. In this way, occurrences such as wrong wind forecasts and grid outages can be translated into real time events (price and/or peak cap changes) that will be communicated by the energy service provider and locally managed by each SDS.

Aside from economic benefits, users could be encouraged to subscribe to DR programs if supported by automated energy management systems (EMS) that minimize costs and provide feedback about energy consumption and charges. Also, in our vision, EMSs should operate autonomously according to grid information signals and users should be able to override the EMS choice, in order to ultimately decide when and how much energy to consume. Finally, EMSs should scale with the number of controlled devices, in order to extend the managed domain to a multi-premise scenario. The proposed SDS, presented in the next section of this paper, deals with those requirements by relying on a distributed logic implemented locally in each controlled smart device. Schmidt and Van Laerhoven define smart devices as “devices that are not ignorant about their environment and context” [9]. In the following, we will limit the meaning of the term to the interface towards other smart devices, the smart grid (signals from the energy service providers), and local meters (consumption signals). More in detail, this paper does not address topics related to home automation, such as the processing of signals from presence or thermal sensors, in order to predict consumption and determine device operation. Also, the paper does not address DR economic aspects, nor does it address the potential acceptance of the proposed DR based SDS by consumers, grid operators, and service energy providers. The contributions of this paper are:

- The design of a distributed framework for the energy management of residential buildings based on energy service provider signals.
- The formulation of the scheduling problem for controlling the operation of smart devices, in order to minimize energy costs under power cap and deadline constraints.
- The simulation-based performance evaluation of an algorithm based on the reordering of requests and online scheduling heuristics.

The third section of this paper presents the scheduling problem. Each local scheduler processes the tasks of the smart device in which it is deployed. This is done by an online cost minimization algorithm with deadlines and power cap constraints. If this algorithm fails to schedule a task, all of the local schedulers in the domain collaborate to reschedule the previously allocated but unexecuted tasks. The rescheduling mechanism might also run when real-time events impose new rates or caps. This represents an offline scheduling problem which, to the best of our knowledge, there exists no solution. We propose an offline heuristic method that first reorders and then allocates all tasks by using alternative scheduling heuristics. The method has been implemented in C language and the simulation-based evaluation results are described in the fifth section of the paper.

Energy management

With the term energy management we refer to the process of controlling the operation of smart devices by scheduling their start (and rescheduling when necessary), in order to satisfy the deadline set by the user, comply with DR power caps, and minimize energy costs according to a dynamic pricing tariff.

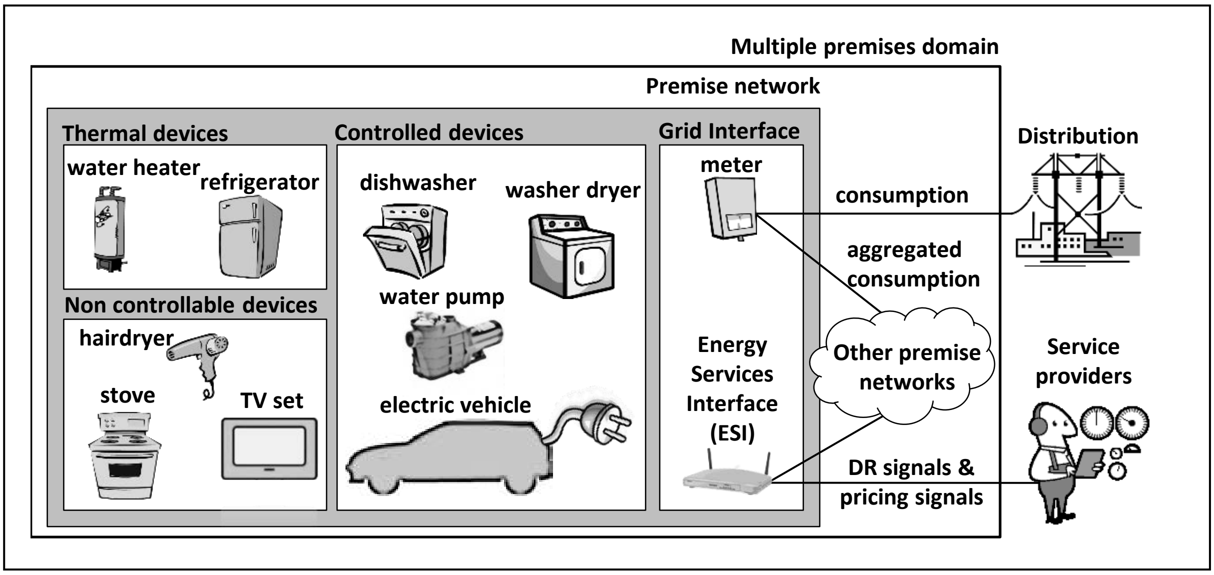


Figure 1 – Reference scenario: components and interfaces of the multiple premises domain controlled by the smart device scheduler (SDS).

To enable energy management and meet the needs of users, grid operators, and energy service providers described in the previous section, we identify the following requirements for the SDS:

1. The SDS should operate in an autonomous way, according to the information obtained from the energy service provider. No direct control signals from the grid should be employed.
2. The SDS should take into account the electric consumption of the non-controlled loads of the controlled domain.
3. The SDS should be distributed in order to scale with the number of controlled devices. The presence of a central controller should not be required.
4. The SDS should manage real time events signaled by the grid. These events may require the rescheduling of already scheduled tasks, as well the interruption of running tasks, in order to adjust the local consumption to the current state of the grid.

In the presented work, we do not address the interruption of running tasks. Also, we consider only those smart appliances with an operation cycle that may be shifted within a time frame of hours, such as dishwashers. We do not address the scheduling of thermal based appliances, such as refrigerators and air conditioners, which are characterized by a periodic operation cycle. The reason is twofold: the potential time shift of these appliances is limited [4]; the duty cycle of those devices is a function of the ambient and target temperatures, thus, in order to effectively manage such appliances, our SDS should integrate home automation functions capable of controlling the target temperature in response to the ambient temperature and the consumer's preferences, as proposed by Le May al. [10], [11]. We assume that the user interface logic has the responsibility of issuing scheduling requests. The operation of such a functional block is out of the scope of this paper and we assume that requests cannot be changed by our system. Finally, we do not consider the integration of policies to fairly distribute the energy among the managed loads. Nevertheless, we believe that a fairness mechanism is needed to properly manage the aggregated consumption of a multi-premises domain.

In the following we use the term timetable as a local repository where the SDS nodes store the information regarding energy price, peak limits, the consumption of non-controlled devices, and the schedule of other controlled devices. The timetable will be further described in the next section.

Real time events may refer to emergency or market situations that are translated into SDS requests to modify the timetable. For instance, events may refer to emergency situations that might impose the drop of the peak cap levels in a very short time frame in order to preserve the reliability of the grid. With the term "real time" we mean that those events must be managed by the SDS as soon as they are received: they may or may not require the rescheduling of tasks.

The reference scenario is presented in Figure 1. The SDS architecture is distributed, so the same logic is implemented in each controlled device (dishwashers, washing machines, dryers, washer dryer

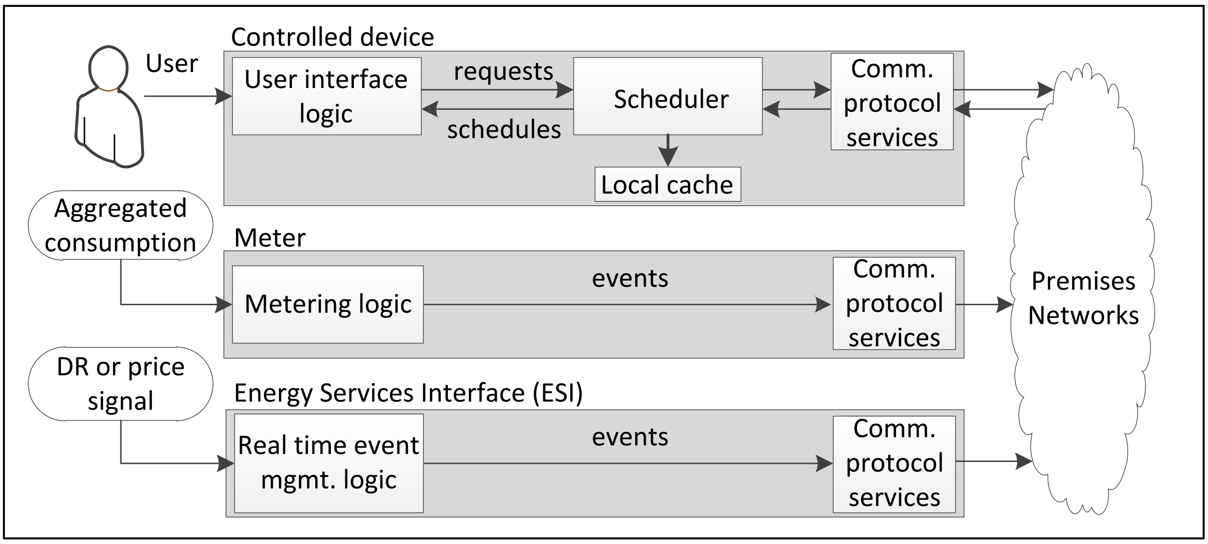


Figure 2 – Functional blocks of the proposed smart device scheduler (SDS).

combos, water pumps, defrost and ice making functions of refrigerators, and EV charging stations). We assume that all components of the premise domain communicate through the domain network. In case of a multi-premise domain, the network includes all of the residential units. The premise interface towards the grid follows the smart grid reference diagram proposed by NIST [12]. It includes two logical blocks: the meter, through which energy usage is communicated, and the Energy Services Interface (ESI), through which the SDS interacts with energy service providers and receives DR (peak cap) and dynamic pricing signals as a consequence of real time events that take place in the grid. The ESI is in charge of relaying this information to the other domain nodes.

The consumption of non-controllable devices stored in the timetable is given by a baseline forecast provided by the meter. In case the effective consumption differs from the baseline by a given threshold, the meter is in charge of communicating the new baseline by broadcasting it within the domain network.

In the case of a multi-premises domain, we assume coordination mechanisms among the ESIs of each premise, in order to relay the grid signals only once, as well as among the domain meters, so that the baseline is evaluated only once on the basis of the aggregate consumption.

Figure 2 presents the functional blocks of the SDS. We have included the user interface logic for controlled devices, the metering logic, and the real time event management logic in order to define the interface of our system. We have introduced the functionalities provided by these blocks above, but their operation is out of the scope of this work. The core block of the SDS is the scheduler. To comply with the requested distributed architecture, we propose a distributed collaborative scheduler. It is collaborative since the local scheduling logic of each node interacts with the other nodes in order to retrieve information regarding the overall domain schedule and to send rescheduling commands. This is done by relying on the services provided by the communication protocol. The timetable is stored in a local cache. Figure 2 also shows how the meter and the ESI broadcast events to the domain network on the basis of aggregated consumption and grid signaling, respectively.

We assume that the peak consumption is evaluated periodically, for instance, in intervals of 15 minutes. In other words, the instantaneous power draw can exceed the peak cap, whereas the constraint is relative to the average value during a particular time period. So we divide the time axis into slots, each having a given energy limit.

The communications protocol must provide services that enable the following actions.

- Scheduling: the scheduling node needs to retrieve the schedules of all other nodes; the ESI and meter need to communicate real time events to all domain nodes.
- Rescheduling: it has to be ensured that only one node can schedule tasks at time; the scheduling node needs to communicate commands to change the schedule of the other nodes.

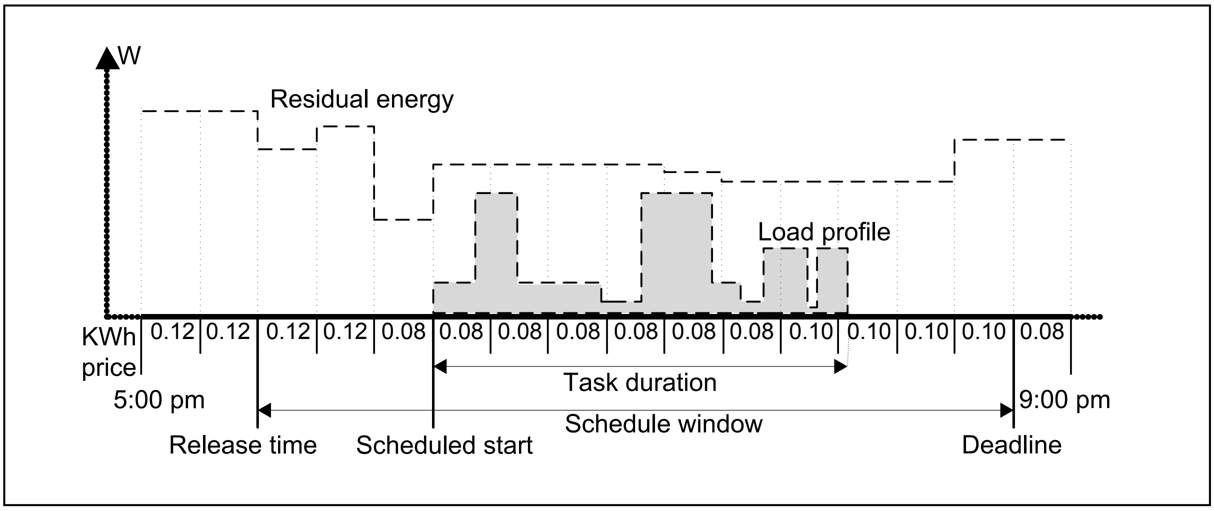


Figure 3 – Timetable with energy prices and residual energy values for each time slot of 15 min, in which an example of appliance task scheduling is reported.

Scheduling

By following the SDS requirements, we identify those for the scheduler functional block:

1. The scheduler should allocate tasks in time by minimizing costs (energy price) and complying with temporal (release time and deadline) and resource (residual energy) constraints.
2. The scheduler should reschedule tasks, in order to react to real time events when necessary.
3. The scheduler should be distributed and each device should implement the same logic.

Scheduling problem

Task requests arrive one at time, as an online problem. Thus we address the problem of allocating the current request. By referring to the timetable presented in Figure 3 we introduce the scheduling terminology.

A task is a process that a smart device needs to perform. We consider appliance and EV recharging tasks. Appliance tasks are characterized by a load profile having a fixed duration (for instance, a task of 120 min that requires 0.2kW for the first 80 min and 1 kW for the remaining 40 min). The duration of a task is expressed in number of timeslots. In Figure 3, a typical dishwasher load profile is used [13]. EV recharging tasks differ from those of appliances in that they require the scheduling of a given amount of energy. The rate at which the energy is provided may vary, but it must comply with a range of admissible power values imposed by the charging technology. So, EV recharging tasks have no fixed duration and that degree of liberty can be exploited by the scheduler.

Each timeslot is characterized by a rate (cost per kWh) and a cap (for example, a power cap of 4 kW for the average consumption that corresponds, in the case of a timeslot of 15 min, to an energy cap of 1 kWh). We define residual energy as the available energy for the scheduling of the current task. For each timeslot, the residual energy is obtained by subctracting the non-controlled consumption forecast and scheduled consumption from the energy cap. In the Figure 3 timetable, the residual energy of each timeslot is given by the area of the rectangle subtended by the time axis and the dashed line.

Tasks must be scheduled to start after a release time and end before a deadlline. Those values are expressed as a timeslot index. We introduce the following definitions:

- The *schedule window* is the time interval [release time, deadline – 1].
- The shift interval is the time interval [release time, deadline – duration].
- The shift time is a duration value given by: *time shift = deadline – duration – release time + 1.*

We assume that tasks start at the beginning of the scheduled timeslot. Also, we assume that the number of timeslots of the local cache timetable is large enough to comply with the task deadline. On the other hand, there is no guarantee on the availability of residual energy.

Online scheduler

For appliance tasks, we can visualize the scheduling problem as a two dimensional online problem, where a load profile figure must be placed within the schedule window in such a way that it does not exceed the residual energy dashed line and minimizes the energy price, as in Figure 3. We propose a brute force approach. Our algorithm consists of finding, within the shift interval, a set of candidate timeslots. Each candidate has a number of consecutive timeslots with enough residual energy to host the load profile. For each candidate timeslot, the energy cost for the entire task allocation is determined. Finally, the algorithm chooses the minimum cost candidate as the scheduled start.

As for an EV request, we adopt a valley filling approach that consists of allocating the task where there is available energy in the timetable. At every iteration step, the algorithm chooses the minimum cost timeslot within the schedule window. For each chosen timeslot, the amount of allocated energy must comply with the range imposed by the charging technology. Also, the remaining residual energy must be higher than a pre-configured parameter, in order to avoid saturating the timetable.

Rescheduling: offline heuristic

In the case a request turns out to be unfeasible, our idea is to reschedule the previously allocated tasks to achieve a better utilization of the residual energy. More in detail, if the online cost minimization algorithm fails, the scheduling node will reallocate all of the previously scheduled but unexecuted tasks of the controlled domain as well as the current task. This represents an offline problem. The rescheduling mechanism might also take place when a real time event imposes changes in the timetable. In this case, the SDS verifies if the overall schedules comply with the new residual energy timetable and if the total allocation cost is the minimum achievable, according to the new price timetable. To the best of our knowledge, the offline problem described above has no solution available in literature. We propose a method based on heuristics. Our method exploits the knowledge of the entire set of requests, even though it ultimately relies on an online scheduling algorithm (with the term “online” we refer to an algorithm that processes one task at time). Our strategy consists of reordering the tasks before scheduling them. Our intuition arises from the observation that by reordering tasks we influence the scheduling outcome. We deduce from the scheduling problem characteristics that:

- If the scheduler allocates the most flexible requests first (characterized by a relatively long shift interval), it may result in emptying those timeslots that are critical for the scheduling of later tasks with more restrictive requirements.
- Different load profiles may be more or less easy to schedule. Thus, choosing to schedule the less regular profiles first may be convenient.

Figure 4 shows two simple non-realistic scheduling cases that demonstrate how the reordering may succeed. In such examples we consider time slots of 1 hour. Presented in (a) are the load profiles of three task requests of the first example. They are characterized by the same [4pm, 9pm] schedule window, that corresponds to the interval of the timetable presented in (b) that also shows energy costs and residual energy values of 5 kWh and 3 kWh. The online scheduler first processes the tasks in the arrival order: first A, indicated with the couple (A,1), then B and finally C. In (b) it is showed how there is no space for B or C, since the algorithm has scheduled A in the slots where the cost is lower. Thus the timetable utilization is not optimal and this is indicated by the exclamation mark. In (c), the same online algorithm achieves a complete feasible schedule after reordering the tasks as (B,1), (C,2), and (A,3). In (d) the four task requests of the second example are presented. They have the same schedule window [4pm, 6pm]. As in the previous example, (e) shows how the scheduler fails in allocating the tasks by following the arrival order. In particular, there is no space left for the D request. In (f) is presented the output of the successful scheduling after reordering the requests as (A,1), (C,2), (B,3), and (D,4).

The proposed reordering heuristic consists of assigning a priority value to each task. Tasks are then sorted in decreasing order of priorities. The task priority is a weighted sum of three different combinations of task parameters that are related to how flexible the request is and to how easy it is to find a feasible schedule. For each task, we define the task priority parameter as follows:

$$priority = x \cdot energy + y \cdot shift + z \cdot shape. \qquad (1)$$

For a given task, *(x, y, z)* are weights for, respectively, the total energy requested *(energy)*, the shift time *(shift)*, and the product of the task duration and the maximum energy requested in a timeslot *(shape)*. The *energy* and *shift* values are normalized by the relative mean values over the *N* requested tasks of the offline problem.

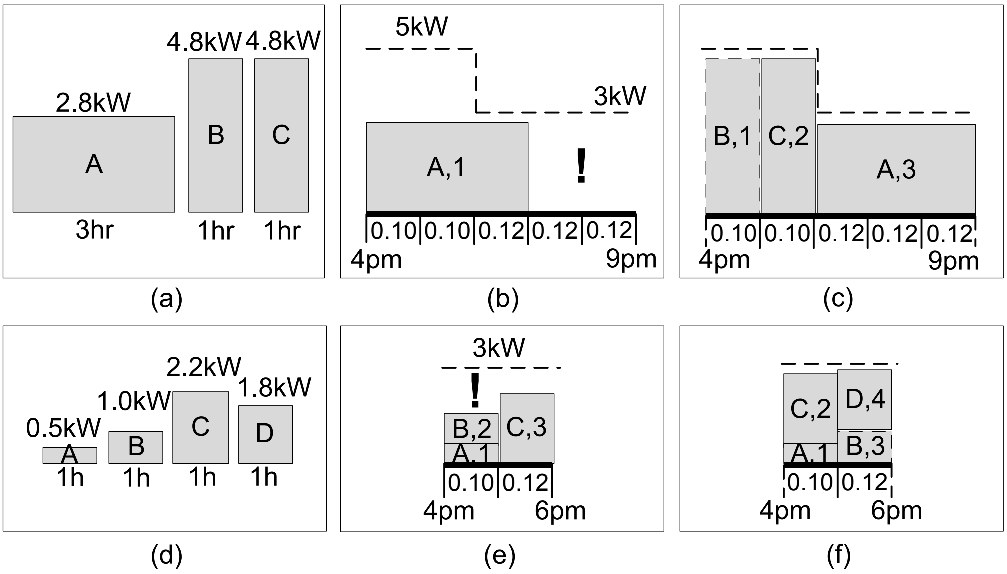


Figure 4 – Two simple non-realistic scheduling cases: motivation for the reordering approach.

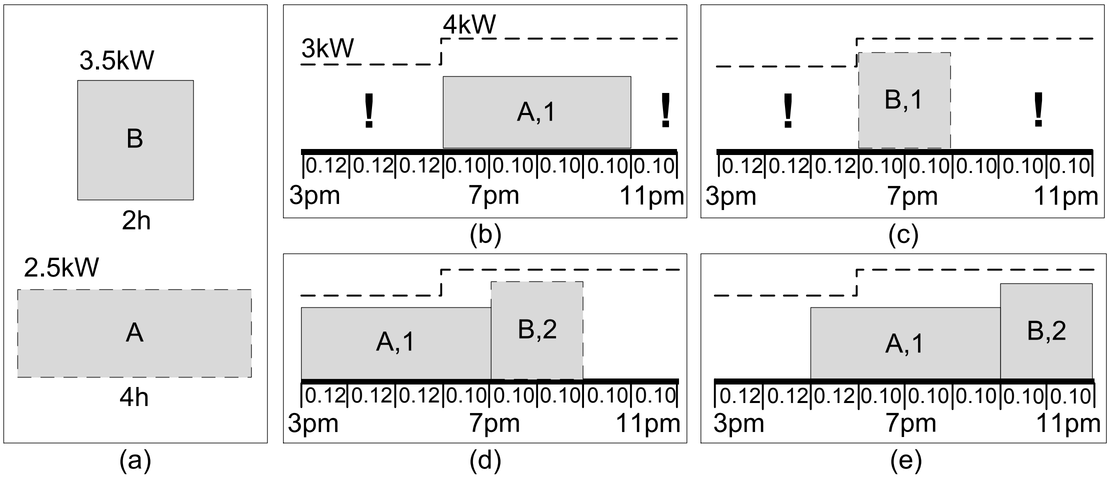


Figure 5 – A simple non-realistic scheduling case: motivation for different scheduling strategies.

There are cases in which a feasible schedule for each of the *N* tasks of the offline problem exists, but no task reordering allows achieving it. Figure 5 reports a simple non-realistic example of this. As in the previous cases, we consider time slots of 1 hour. Two requests are presented in (a), A and B, that have the same schedule window: [3pm, 11pm]. Presented in (b) is the timetable as well as the outcome of the online algorithm (which just tries to minimize the cost) after processing the A task: there is no space left for B. It should be noted how the algorithm uses the first available slot that minimizes the cost (to say, it picks the 6pm one instead of 7pm). This is reasonable since the SDS should try to minimize the delay annoyance. In (c) we have the output of the offline reordering approach. The requests are reordered so that the tallest task, B, is processed first by the online algorithm. As shown, after allocating B, there is no space left for A either. In (d) we have the schedule given by a modified online algorithm. It processes the tasks by their arrival order. Besides aiming at cost minimization, this algorithm tries to reduce the timetable fragmentation by determining a schedule that minimizes the resulting residual energy. This is done by considering a cost tolerance of 0.10 cost units. That cost tolerance sets a constraint to quantify the trade-off between cost minimization and fragmentation reduction. As to say, “find an alternative schedule that reduces the resulting residual energy, but do not spend more than 0.10 compared to the minimal cost schedule”. By choosing the 3pm slot for the task A, the algorithm is spending 0.06 cost units more, but the resulting residual energy allows the scheduling of the task B. Finally in (e) we have the optimal solution, achieved by the same “minimal residual energy” online algorithm used in (d), but with a cost tolerance of 0.3 cost units.

The situation presented in the previous example motivates the use of two scheduling heuristics in alternative to the brute force cost minimization algorithm. They trade the cost minimization objective for a better allocation of the residual energy timetable. By following the previous example, for a given task request, those heuristics first obtain the schedule candidates and the minimum cost schedule, in the same way as the cost minimization algorithm does. They then consider the set of schedule candidates whose energy charges differ from the minimum one by less than a given cost tolerance. Among those candidates, a timeslot is chosen as the final scheduled start by following two different criteria: Max Min Residual Energy and Min Total Residual Energy.

The first scheduling criterion is such that the chosen schedule is the one that shows the maximum minimum residual energy value. This value is determined over the timeslots necessary to allocate the load profile. The minimum residual value $m_i[j]$ of the timeslot j for the scheduling of task i is:

$$m_i[\mathrm{j}] \stackrel{\text{def}}{=} \min_{k\in[j,j+l_i-1]} \{ R[\mathrm{k}] - e_i[\mathrm{k}-\mathrm{j}+1] \}. \tag{2}$$

Where l_i is the duration of task i expressed in number of timeslots, $R[k]$ is the residual energy of the timeslot k, and $e_i[j]$ is the energy requested by the task i in the timeslot j of its load profile. If we indicate the minimum cost by c, the cost of allocating the task i in the timeslot j by $c_i[j]$, and the cost tolerance by p, we can define the set of schedule candidates S_i of the task i as:

$$j \in \mathcal{S}_i \qquad j \textit{ is a schedule candidate and } c_i[\mathrm{j}] - c < p\,. \tag{3}$$

The criterion thus imposes to choose as the scheduled start the timeslot s_i given by:

$$s_i = \mathrm{j}: \quad \max_{\mathrm{j}\in\mathcal{S}_i} \{ m_i[\mathrm{j}] \}. \tag{4}$$

We refer to this scheduling method as Max Min Residual Energy (MMRE). If we consider the scheduling problem in a graphical way (as a two dimensional problem), by adopting this criterion, the scheduler avoids fitting the figure where the space is little. On the contrary, this method tries to allocate the load profile shape where the space left for future requests is bigger. Following this criterion may result in choosing timeslots with greater residual energy or, more interestingly, timeslots in which the particular energy profile finds a better fit. In this way, the resulting timetable will more likely be able to host future tasks characterized by a long duration.

The second scheduling criterion goes in the opposite direction. It requires choosing as the scheduled start the timeslot that has the minimum total residual energy value. We define the total residual energy of the timeslot j for the scheduling of the task i as:

$$w_i[\mathrm{j}] \stackrel{\text{def}}{=} \sum_{k=j}^{j+l_i-1} R[\mathrm{k}]. \tag{5}$$

So, the schedule is obtained by:

$$s_i = \mathrm{j}: \quad \min_{\mathrm{j}\in\mathcal{S}_i} \{ w_i[\mathrm{j}] \}. \tag{6}$$

In this way, by using the same graphical visualization of the scheduling problem, the scheduler tries to allocate the load profile shape where the available space is just enough to host it, in order to obtain a better packing. The scheduler does not care about the remaining space for future figures to be allocated. So this method is more suited for cases in which the task requests are characterized by a large shift interval. We refer to the heuristic based on this criterion as the Min Total Residual Energy (MTRE) since it tries to minimize the residual energy left.

To summarize, for the offline problem of scheduling N tasks, we propose a heuristic method that consists of reordering the task requests and schedule each of them by using an online algorithm. Besides the online cost minimization algorithm, we propose three scheduling heuristics: 1) MMRE, 2) MTRE, 3) RND. The last one consists in randomly choosing, for each on the N tasks, one method between MmRE and mTRE, with equal probability.

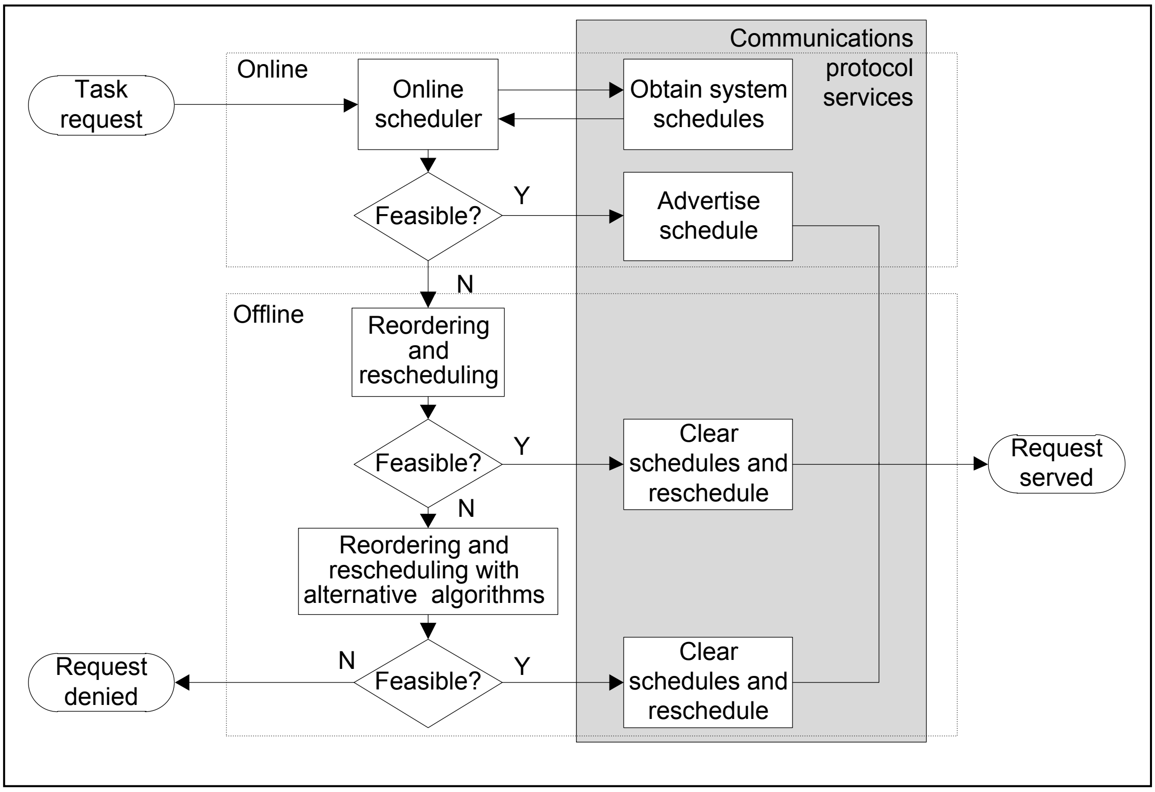


Figure 6 - Distributed scheduling: process flow and communication services.

In Figure 6, we illustrate the process flow of the scheduler and the required communication services. This picture places the brute force cost minimization algorithm (represented by the online scheduler block) together with the offline method based on the reordering and alternative online scheduler heuristics. The online scheduler receives the task request from the user interface logic block. Then it advertises the start of the scheduling process in the SDS domain, in order to avoid potential scheduling conflicts, and retrieves the set of system schedules from all other smart devices to update the timetable. If the scheduling process succeeds, the scheduler advertises its new schedule to the other devices by broadcasting a message. The schedule is also communicated to the user interface logic block. In case the schedule is not feasible, the offline method reschedules all previously allocated tasks. First, the tasks are reordered and scheduled with the cost minimization algorithm (the same one used in the online part). If this method also fails, the scheduler will employ alternative online algorithms (MMRE, MTRE, or RND). If the one of the offline approach succeeds, the scheduler will rely on the communications protocol to manage the rescheduling process that will require broadcasting a control message to let the other devices reset their own schedule timetable. After that, unicast messages will be employed to communicate the new schedules to the rescheduled devices. Finally, if the offline method does not succeed in scheduling all tasks, the current request is denied, otherwise the schedule outcome is communicated to the user.

Performance evaluation

We choose to simulate the SDS since an analytical model of the offline scheduling problem is not available. The objective of the performance evaluation is to verify the efficacy of the rescheduling-based method that executes whenever the online algorithm fails in scheduling a task. In particular, the proposed method must reschedule all the previously scheduled tasks plus the current one (offline problem). If at least one of those tasks is not scheduled, the current request is denied. As a consequence, we evaluate the ability of the rescheduling method to entirely schedule a set of tasks.

The simulated system consists of the scheduler block presented in Figure 2. The reference scenario is a multi-premises domain. We assume that the timetable information is completely available. We have implemented the scheduler block by following the process flow presented in Figure 6. Also, in separate tools, we have implemented the online brute force scheduler (which is a part of the scheduler block), an optimal offline scheduler based on a greedy iterative tree search algorithm, and a workload generator. All of the tools have been developed in C language.

Table 1 - Comparison between scheduler methods: percentage of sets entirely scheduled.

Interarrival rate (λ)	Feasible sets	Rescheduling method	Online scheduler
0.4	76.2%	90.1%	14.5%
0.6	66.9%	87.2%	12.2%
0.8	62.2%	86.1%	11.6%
1.0	56.5%	85.4%	11.3%
1.2	54.1%	84.7%	11.1%
1.4	52.3%	84.1%	11.0%
1.6	51.2%	83.4%	10.8%

The input of the three scheduler tools consists of four different files containing the energy prices, the power caps, the non-controlled consumption, and the task requests, respectively.

The workload generator provides stochastic sets of task requests. The tasks are related to different realistic load profiles of the following appliances: dishwasher, tumble dryer, washing machine, washer dryer, pool pump, well pump, dehumidifier, and the automatic defrost mechanism of refrigerators. We do not consider EV charging tasks since the valley filling algorithm has a major impact on the residual energy and, consequently, it becomes very difficult to analyze the scheduler performance. For each set of tasks, the workload generator creates a CSV file containing requests characterized by a load profile (represented by a duration value and a data structure indicating the power request over time), a release time, and a deadline. The temporal values are expressed in number of timeslots. The processing follows a bottom-up approach. For each appliance load profile, a bounded Pareto RNG determines the relative number of requests and, for each of these requests, an exponential RNG determines an interarrival value and a deadline delta. The release time of each task is determined by accumulating the interarrival values of the previously processed tasks. The deadline is then obtained as the sum of the release time, the load profile duration, and the deadline delta.

In the presented experiment, we compare the outcome of the scheduler block, the online scheduler, and the optimal scheduler. The adopted metric is the percentage of entirely allocated sets of tasks. The workload is made of 5000 sets of 12 tasks, so the workload generator considered only the first 12 tasks of each set. In this case, the choice to use such a low number of tasks is due to the factorial computational complexity of the greedy scheduler algorithm that would not execute in a reasonable time with larger sets of tasks. The rate parameter of the exponential distribution of interarrivals (indicated by λ) is the experimental factor, in order to verify the influence of the workload. Increasing λ results in smaller interarrivals, so the schedule windows of different requests will more likely overlap and the number of sets that cannot be entirely scheduled will increase. The timetable time range is 48 hours, divided into timeslots of 15 min. As for the energy prices, we employ a Time of Day tariff that consists of four periods of 6 hours over a day, with prices equal to 0.6, 0.8, 1.2, and 1.4 cost units, respectively. Power caps and the non-controlled consumption are chosen in such a way to bring the timetable close to the saturation, according to the workload. Regarding the parameters of the rescheduling method, the *x*, *y*, and *z* weights of the priority reordering formula presented in Equation (1) are chosen as 2, 3, and -1, respectively. Those values were obtained by a previous experiment for the tuning of the system. The cost tolerance *p* presented in Equation (3) is set to 5 cost units.

The results are presented in Table 1. The results of each experiment run are reported in different rows. The first column presents the λ factor used to obtain the 5000 task request sets of each run. The second column reports the outcome of the optimal scheduler. That value corresponds to the percentage of feasible sets of tasks. It is evident how this value drops when the workload becomes heavier. The third and fourth columns give the percentage of feasible sets that are successfully scheduled by the proposed rescheduling method and the online algorithm, respectively, in order to estimate how close the two algorithms get to the optimal solution. In the first row, for a workload with interarrivals with λ = 0.4, the percentage of feasible sets of tasks is 76.2%. So, among the 5000 sets of requested tasks, 3810 sets are completely schedulable. Of these 3810 sets, the online scheduler is capable of entirely allocating only the 14.5%, whereas the system scheduler allocates the 89.5%. With heavier workloads, the performance of the two scheduler methods drops, as shown in the other rows of the table. We can conclude how the rescheduling mechanism significantly increases the number of schedulable tasks when compared to the online approach (brute force cost minimization algorithm). Also, we can affirm that the scheduler performance varies significantly with the workload.

Related work

The following works address demand side management (DSM) and scheduling techniques. The integration of building automation technologies for energy efficiency and DSM have been addressed in [10] with a centralized architecture where the main component is the Unified Hub that receives utility price signals from the smart meter. The signals are then relayed to appliances that may control themselves or delegate the DR controls to the hub. The same research group proposes an energy management system based on the previous architecture that has the objective of maximizing the user comfort while complying with energy consumption constraints [11]. The system is based on a blackboard architectural pattern and includes appliance usage detectors, sensors, and other components. A collaborative recommender is in charge of selecting the suitable building control algorithms for being installed in the blackboard. Our work does not address home automation functions. We focus on improving the electricity demand responsiveness by peak cap DR signals.

The integration of smart appliances into the smart grid is addressed by the Whirlpool Smart Device Network (WSDN) technology [13]. WSDN consists of a complex DR architecture that includes both the house and smart grid domains. Three levels of DR operation are proposed: (1) appliances individually respond to signals; (2) the operation of all smart devices is coordinated by a home energy management system; (3) the Smart Grid coordinates the DR of the houses through the Internet. The Authors state that consumers should ultimately control how appliances response to the DR signals. The main difference with our architecture is in the fact that appliances are managed by a centralized Smart Device Controller. The paper also provides typical load profiles of several appliances.

A scheduling problem for tasks characterized by deadlines and a given power demand is presented in [14]. The objectives are peak shaving (peak shift in a short time frame) and cost minimization. The reference DR program is based on local control through real time pricing signals. The scheduling is analytically formulated as a min-max problem (NP-hard, since it is a particular case of a well-known problem). The proposed algorithm is based on the Longest Process Time greedy search algorithm, but processes the task with the largest energy consumption first according to the cumulative cost of each timeslot. Through an analytical formulation, the Authors prove that the algorithm finds near optimal solutions. The benefits of energy storage are also considered. We did not provide an analytical formulation of our scheduling problem, which is more complex since we also consider power peak constraints. We use a similar a max-min approach for the proposed MMRE heuristic.

A DSM distributed scheduler for domestic energy consumption (smart appliances and EVs) is presented in [15]. The reference scenario is a time of use DR program that controls the aggregated consumption of multiple houses. The scheduler implemented in each Smart Meter and the local algorithm relies on the knowledge of the current overall schedule of the domain. The Authors present a formulation of the problem based on Game Theory. The distributed algorithm aims at reducing the total energy cost and the peak to average ratio. Thanks to the analytical formulation, it is shown that the system reaches the global optimum when the local algorithm reaches the local optimum. The proposed distributed architecture is similar to our collaborative scheduler. Also, we consider a multiple house scenario. Nevertheless, the Authors do not consider peak caps in their scheduling problem.

The scheduling of periodic appliances (such as refrigerators and air conditioners) through the control of their duty cycles is addressed in [16]. The proposed algorithm (Tetris-like) sets the phase of the tasks related to a common time period in order to achieve peak shaving. The Authors present the problem of how to reduce the cooling of multiple air conditioners in a fair manner and propose a max-min approach based on temperature. In our work, we address the scheduling of tasks that can be shifted in a time frame of hours, by minimizing cost and complying with deadlines and peak caps.

Summary and future work

This article presents a smart device scheduler that enables peak shift in residential buildings by controlling the operation of smart appliances and electric vehicle charging stations. Our system tackles the problem of improving the level of responsiveness of domestic electricity demand by offering an autonomous rescheduling mechanism that reacts in real time to dynamic pricing and peak cap based demand response signals. The scheduler is distributed and collaborative and does not require a central controller, thanks to the services provided by a communications protocol. We formulate the offline scheduling problem related to the rescheduling process, characterized by deadline and power peak constraints. To the best of our knowledge, there is no solution available in literature. We propose and evaluate a heuristic-based method. The presented results, obtained by simulating the system, show how the rescheduling method increases the number of successfully allocated tasks when compared to a system that only uses an online scheduler. In particular, the proposed method achieves a successful schedule of up to 90% of the sets of tasks that are shown to be entirely schedulable by an optimal scheduler (greedy), whereas an online scheduler is capable of scheduling up to 15% of the same sets. Future research work consists of 1) defining a mechanism for the interruption of running tasks, 2) addressing the need of a fairness mechanism to allocate energy among multiple houses, 3) formalizing the specifications of the communications protocol, and 4) building a prototype of the smart device scheduler. We also believe that the definition of an analytical model of the offline problem could be an important research contribution, which would enable a study regarding the existence of an optimal solution for at least a subset of the original problem.

Acknowledgements

We would like to thank our anonymous reviewers who have provided helpful comments for improving the paper.

References

[1] A. Chardon, O. Almén, P.E. Lewis, J. Stromback, B. Château, “Demand Response: a decisive breakthrough for Europe. How Europe could save Gigawatts, Billions of Euros and millions of tons of CO2”, Capgemini consulting, 2008.

[2] “Annual Energy Outlook 2010 – with projections to 2035”, U.S. Energy Information Administration, April 2010.

[3] “Final electricity consumption by sector (ENER 018)”, European Environment Agency, September 2010.

[4] R. Stamminger, “Synergy Potential of Smart Appliances”, SMART-A Deliverable 2.3, 2008.

[5] EDISON project website http://www.edison-net.dk.

[6] H. Fraser, “The importance of an active demand side in the electricity industry”, The Electricity Journal, Elsevier, Volume 14, Issue 9, pp. 52-73, November 2001.

[7] S. Braithwait, “Behavior modification”, Power and Energy Magazine, IEEE, Vol. 8, Issue 3, pp. 36-45, May-June 2010.

[8] B. Nordman “Beyond the Smart Grid: Building Networks”, Environmental Energy Technologies Division - Lawrence Berkeley National Laboratory, May 2010.

[9] A. Schmidt and K. Van Laerhoven, “How to build smart appliances?”, IEEE Personal Communications, Vol. 1070-9916/01, pp. 66-71, August 2001.

[10] M. LeMay, R. Nelli, G. Gross, and C. A. Gunter, “An integrated architecture for demand response communications and control”, Proceedings of the 41st Annual IEEE Hawaii International Conference on System Sciences (HICSS '08), Waikola, Hawaii, January 2008.

[11] M. LeMay, J. J. Haas, and C.A. Gunter, “Collaborative recommender systems for building automation”, Proceedings of the 42nd Annual IEEE Hawaii International Conference on System Sciences (HICSS '09), Waikola, Hawaii, January 2009.

[12] “NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0”, NIST Special Publication, NISR, January 2010.

[13] T. J. Lui, W. Stirling, H. O. Marcy, “Get Smart”, Power and Energy Magazine, IEEE, Volume 8, Issue 3, pp. 66-78, May 2010.

[14] J. Xiao, J. Y. Chung, J. Li, R. Boutaba, J W. Hong, “Near Optimal Demand-Side Energy Management Under Real-time Demand-Response Pricing”, POSTECH University, Pohang, South Korea, 2010.

[15] A-H. Mohsenian-Rad, V.W.S. Wong, J. Jatskevich, R. Schober, “Optimal and Autonomous Incentive-based Energy Consumption Scheduling Algorithm for Smart Grid”, Proceedings of the IEEE Conference on Innovative Smart Grid Technologies, January 2010.

[16] J. Howard, H. Ham, N. F. Maxemchuk, “Smart Air Conditioners”, Proceedings of the Global Smart Grid Symposium, US-Korea Conference on Science, Technology, and Entrepreneurship (UKC), August 2010.

Energy Management with smart appliances

Paolo Falcioni, Céline Hérion, CECED

Abstract

Consumers' involvement in Smart Grids is a key element in ensuring the successful penetration of the new technology. An evolution of the electricity market structure is needed to empower consumers and enable them to take fully the benefits of Smart Grids and Smart Appliances. Legislation is required to ensure a balanced distribution of benefits across the entire energy value chain.

Energy management begins at home

Consumers have a fundamental role to play in changing Europe's overall energy consumption patterns: user choices and behaviours participate in determining tomorrow's landscape. At home, the largest share of energy is dispensed to appliances, with air and water heating in the first instance. The energy conscious use of household appliances can significantly contribute to the European Union's climate objectives.

When addressing consumption trends, governments have, until now, favoured a stepwise approach focusing on efficiency standards and labelling requirements. Regulatory instruments have made a significant contribution to improving product efficiency. The promotion of the best available technologies has to continue in order to ensure the uptake of the most energy efficient products since energy efficiency is THE area in which consumers can make a difference. But considering the dimension of today's environmental, energy and societal challenges, current markets have fallen short of producing innovative instruments to make a ground-breaking step forward in managing energy demand.

Smart grids are the next stage: an intelligent grid that balances interests, takes account of consumers' needs and empowers them to manage their own energy use. Considering they account for the largest share in electricity consumption in residential premises [1], appliances have a significant contribution to make to demand-side management. Smart appliances are built to interact with an intelligent grid. They are built to respond to the strictest legal, technical and safety requirements while ensuring minimum pressure on users and their lifestyle. With smart appliances, smart grids could participate in encouraging behavioural changes and curtailment of consumption upon request, both at individual and collective level in the respect of each household. Contrary to other products, smart appliances are flexible as to time of use and usage pattern. They can, for instance, reduce their consumption in response to an emergency signal and reduce the risk of black out. Such technology is available today and is expected to play an active role in ensuring the continued quality of a seamless supply of energy.

Some strategies have to be developed to put in place an energy model that goes beyond a viable grid. To implement a truly smart grid, progress towards a system that works with – not against – consumers has to be made. The best implementation strategies that ensure further progress necessarily imply an open and committed cooperation among all stakeholders to evenly share costs and benefits of the smart grid/smart appliance deployment. In other words, legislation must guarantee a fair transfer of the value, created by smart appliances, to consumers who offer an optimization service.

Smart appliances: a technology ripe for picking

Smart appliances: benefits and use cases

Optimizing energy use at home with smart appliances can deliver benefits to the society at large.

Authorities would take decisions maximizing public funds by lessening the need for new conventional power plants, contributing to the European and global climate objectives and minimizing the impact on industries' competitiveness while stimulating new technologies.

Energy suppliers would value an alternative to generation and transmission investments. On the one hand, they would, in practice, participate in limiting the use of fossil-fuel power plants to fill peak needs, by minimizing the load on the power distribution network in high demand periods. On the other, they would be able to fill the availability gaps or to maximize the benefit of inconstant supply from renewable energy sources.

Advantages to the consumer would depend on the appliances' functionalities and their resulting savings, themselves directly contingent to variable energy tariffs.

In one way or another, every product group can make a contribution to demand-side management, with various levels of smart sophistication. Basic features of household appliances would consist in displaying information on the volume of consumed energy and on its price. More advanced smart appliances could fully interact with the distribution network, controlling loads in relation to the volume, stability, price and power peak signals and supporting forecasts. Smart Appliances would thus react to Time of Use signals and adopt intelligent power management strategies varying against different configuration of events or needs:

1. to minimize the load on the power distribution network, for example, in case of peaks or in order to shift the energy load;
2. to best use the surplus in the power generation network, storing the excess capacity in refrigerator/freezers or in hot water boilers;
3. to maximise the benefit of variable renewable sources, like wind and solar power generation.

Smart appliances would have a major influence in controlling energy demand as part of a smart grid that would ensure the security and the quality of a well-designed, seamless, energy supply system. This truly intelligent system would lead to minimal impact on users and their lifestyle. On the contrary, automated random or abrupt remote control of appliances would imply unsolicited disruptions that could be assimilated to a general power failure. Prospects of external control would turn an intelligent product into a passive mode leading to serious concerns notably on domestic comfort, the respect of consumers' freedoms and safety issues.

Consequently, user needs and industry's know-how have to be considered. The appliance's properties have to be respected and users must be able to choose and to be in control of their appliances. If lacking consent from consumers, forced access to products from outside the house must be proscribed. However, if the user agrees to accept external control by the energy supplier, clear conditions must be outlined and clear incentives should be forthcoming. Self-contribution would give an advantage to the whole society but would also result in drawbacks for the benevolent consumer. Voluntary participation thus deserves appropriate and clear compensation. A suitable benefit would even out the economic profit of demand-side management among market actors. Indirect measures such as the implementation of dynamic pricing through differentiated tariff schemes would provide a benefit to users.

In any case, the provision of accurate information on energy consumption and tariffs is the step required for more active participation from citizens. Indications would for example confirm the amount of renewable energy available on the network over a defined period, allowing users to make informed choices and certainly choose more environmentally conscious options. Therefore, robust incentives are needed for those who adapt their energy consumption patterns to the available tariffs.

Smart appliances: in need of smart legislation

The energy markets are not yet suited for the empowerment of consumers. Information on the possibility to activate demand-side management is scarce. Even when that was possible, the economic benefits are not enough to motivate end-users.

When looking at the standardization landscape, a lot of work is in progress, but the time to market of standards is sometimes not fully adequate to market needs.

Current available tariffs are starting to differentiate between a “high” and a “low” electricity price. It is a good indication that an evolution in consumer behavior is sought. More should be done to create an attractive energy efficient market.

Users have to be informed and should have the capability to participate in energy management. Meter smartness should thus go beyond traditional automatic meter reading. It should also enable a flow of information and energy both to and from the energy user..

Today’s energy market structure is, as one can see, not sufficient to motivate the purchase of the most energy efficient and energy intelligent appliances and consumers are not empowered to participate to Europe’s climatic goals.

A smart energy market is the answer to empower consumers

A smart grid cannot bypass energy efficiency services anymore. Consumers have to be involved in the development of a renewed energy system. To this end, the smartest approach is to offer a premium to efficiency and savings.

These aspects have been recognised at EU level, by numerous stakeholders and by the EU Institutions themselves.

The Task Force on Smart Grids, put in place by the European Commission to receive recommendations on policy/regulatory aspects and implementation of the Smart Grids, is taking due account of this issue. At the end of December 2010, it was clearly acknowledged that “a large number of stakeholders in the Task Force recognised certain needs for specific Smart Grid EU legislation regarding consumers” [2].

Similarly, the Energy Efficiency Plan 2011[3] foressees requirements on information provision and services in order to ensure a market open to energy efficiency technologies and solutions. Information to consumers should be improved and their rights implemented. The appropriate first move has been made by focusing on measures to empower consumers to access energy efficiency services and demand management. Smart appliances are seen by both the industry and European policy makers as an integral part of the development of smart grids. This understanding should move from a gentleman’s agreement to the deployment of a policy.

.

References

[1] Odysee Mure project. *Energy Efficiency Indicators in Europe*. Can be downloaded at: http://www.odyssee-indicators.org/reports/ee_households.php

[2] European Commission, Smart Grids Task Force, *Steering Committee minutes,* 17 December 2010, Brussels, http://ec.europa.eu/energy/gas_electricity/smartgrids/taskforce_en.htm

[3] European Commission, Communication Energy Efficiency Plan 2011, 8 March 2011, Brussels, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0109:FIN:EN:PDF

Fostering product innovation for water saving, treatment and reuse in household appliances: towards green washing solutions

***Paolo Faraldi**, Luca Bossi, Leonardo Arteconi, Annalisa Ciarletta, Serena Graziosi*

Affiliation: Indesit Company, Innovation & Digital Design Department;

Michele Penza*, Riccardo Rossi, Patrizia Aversa, Domenico Suriano, Gennaro Cassano, Marco Alvisi, Valerio Pfister, Domenico Di Maio, Rocco Pentassuglia

Affiliation: ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Brindisi Technical Unit of Technologies for Materials;

Salvatore S. Emmi, Claudia Castro, Biagio Esposito, Michela Saracino.

Affiliation: Istituto per la Sintesi Organica e la Fotoreattività, ISOF-CNR, Area della Ricerca CNR;

Guido Sassi*, Pietro Palmisano, Milena Salvo

Affiliation: Politecnico di Torino, Dipartimento di Scienza dei Materiali e Ingegneria Chimica-DISMIC

Abstract

Household appliances such as clothes washing and dishwashing machines use 10 to 30% of total domestic water consumption. Currently available washing machines do not provide systems to store and reuse wash and rinse water, or to filter dirt and residual detergents from drain water, or to monitor water quality to detect residual substances. This paper provides results of a three-year research project to develop advanced technologies to recycle waste water and reduce water and energy used by clothes washing machines. The project goal is to reduce energy and water consumption by 25% to 30%. To reach this goal three complementary technologies were investigated and demonstrated: (1) mechanical water filtration; (2) Advanced Oxidation Processes (AOP) for purification/sanitation, and (3) water quality monitoring devices to detect whether substances or residuals are present. A "modular" approach was applied so each solution can be implemented separately or incrementally. Water filtration tests showed positive results with polymeric filters. AOP-based methodologies were effective in chemical oxygen demand (COD) reduction and in degradation of anionic surfactants and nonionic surfactants. Ozone and UV can also be used as anti-microbial agents. Water quality monitoring of COD and its correlation to water conductivity enables different water reuse algorithms (cycles). All technologies were tested separately demonstrating the possibility of a modular approach for the final implementation. Results for clothes washers can be applied to other appliances such as dishwashers. These results provide important data for designing a dedicated "green washing" system.

1 - Introduction

Potable water is essential for human survival and important for many sectors of the economy. Water availability varies seasonally and annually in many countries of the world due to climate change, increasing human population, increasing economic development, and inefficient use of water. In such a context, household appliances play a significant role in water consumption since water use accounts for 10-30% of total household consumption in developed countries [1]. Specifically, about washing laundry it has been demonstrated that the volume of water used for laundry washing influences the total water consumption of household in all countries significantly (5% to 18%) [2]. Then, it is not a case that the availability of energy and water efficient horizontal-axis washing machines in the North American market is growing: H-axis washers typically use one-third to two-thirds less energy, water, and detergent than vertical-axis machines [3].

In order to reduce water consumption, several product innovations were introduced by household appliances manufacturers by monitoring and adjusting water use and wash times. Specifically, Indesit Company (Europe's second biggest manufacturer of household appliances by market share), the promoter and coordinator of the research activity discussed in this paper, has recently introduced eco-programs for washing machines using water at room-temperature together with solutions optimising the use of water and energy on the basis of the quantity of laundry loaded. Despite the actions already undertaken, a radical technological leap forward is still missing. For this reason, Indesit Company, in particular the Innovation & Digital Design Department, decided to start a research activity focused on innovative technological solutions for water re-used in future washing cycles. This research activity is part of a three-years research program (2009-2012, http://www.energyappliances2015.it) funded by the Italian Economic Development Ministry, which aims at providing a new range of highly innovative household appliances, characterized by a considerable reduction in energy and water use (ranging from 25% to 30%) for all product lines, dealing with food preservation/preparation and cloth/dish cleanness. Specifically, the research activity discussed in this paper was carried out in collaboration with a multidisciplinary research group whose members (more than 20) belong to Italian Universities and research centres such as Politecnico di Torino, Enea and CNR-ISOF (Table 1).

Table 1. Project Research Activities (Tasks) and owners

Project Research Task	Owner	Location
Water Storage and Filtration (mechanical treatments)	Politecnico di Torino	Torino - IT
Advanced Oxidation Processes (chemical treatments)	ISOF - CNR	Bologna – IT
Water quality detection (sensing)	ENEA - CR Brindisi	Brindisi – IT
–Feasibility assessment and Project coordination; –Technologies integration (working prototype building)	Indesit Company SPA	Fabriano - IT

The following solutions were addressed by the project: (1) storing water deriving from the final rinse to be used in following washing cycles, under specific conditions (lack of coloring agents, bleach residues, bacteria loads etc.); (2) filtering water for retaining dirt residues or detergent insoluble components; (3) treating water by innovative oxidation processes to decompose washing deriving pollutants. Demonstrators were implemented, aiming at experimentally quantify washing performances through standard and tailored assessing procedures.
In order to provide a clear description of the research activity main objectives, the paper begins with a section describing the state of the art on washing technologies in the household appliances industry. The next section integrates the adopted methodologies together with the state of the art on water treatment and quality monitoring/sensing technologies. The fourth section discusses how such methodologies were implemented in physical prototypes, while the fifth one examines the procedures applied to perform experiments. Finally, in the sixth paragraph, the applicability of the approaches proposed is assessed by the analysis of the experimental results. Findings, limitations, and implications of the research are discussed in the final section.

2 - State of the art: "as is" on appliances

In the specific case of a washing machine, it happens quite frequently that an improper use of the appliance, does not only involve electric energy, but also water and detergent. Quite often, in fact, the user introduces an excessive quantity of detergent to ensure expected cleaning performance of the laundry. This not only increases the quantity of polluting residues released to the environment, but it also requires an increased quantity of water to rinse the clothes adequately. In particular, water consumption depends upon the type of garment load, its quantity and the number of rinses associated with the program selected by the user. Washing machines currently on the market are not provided with systems for storing and reusing wastewater. No systems are available for filtering dirt and residual detergents from water wash cycle. Approaches currently implemented by household appliances manufactures are similar to the one already in use in the Indesit Company *New Aqualtis®* range with *Care Technology®* where, thanks to a linear pressure switch, an algorithm can recognize the quantity and type of garments loaded and limit, accordingly, the number of mechanical actions of the drum (by up to 42%) and the quantity of water used (by up to 29%), eventually achieving an energy saving (10%).

A patent research on this subject (*water storage – filtration – re-use*) shows that a clear trend exists: the number of filed patents increased especially in the last 5 years, demonstrating the strong interest of manufactures in the water issue (Figure 1).

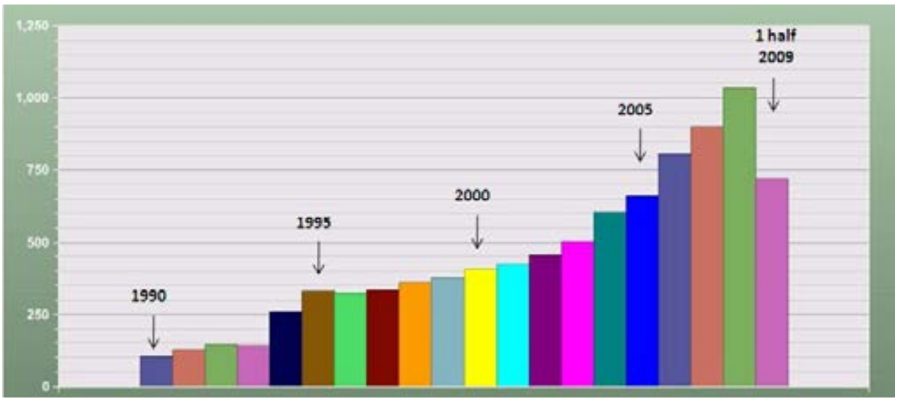


Figure 1: Number of patents filed on - water, storage, filtration, reuse- subject for all type of appliances. Remarks: for 2009 only the first 6 months data are available. Source: Thomson database [4]**.**

Specifically, for a washing machine of 6-7 kg load capacity, water consumption is mainly split in the following two stages: (a) washing phase, during which dirt is removed from clothes and is diluted inside water through mechanical/thermal/chemical actions; (b) rinses: generally 2 (in some cases 3) to remove residual detergent and dirt from clothes. For the wash phase, the approximate amount of water loaded inside the basket is maximum 3 liters/kg; such amount can vary upon load composition: for example, it increases for highly water absorbent materials (e.g. sponge). Considering reference cycles, an average of 25 liters for the washing phase and 45 liters for the two rinses can be considered. The main water consumption occurs during the 2 rinses cycles (this is true for the best part of cycles). For this reason, the research partners put efforts on re-using completely or partially rinse water, as it will be hence discussed in the next session.

3 – Methodology

Figure 2 is a schematic of the methodologies and approaches used to design a "green" washing machine concept, able to help the environment by wasting less water.

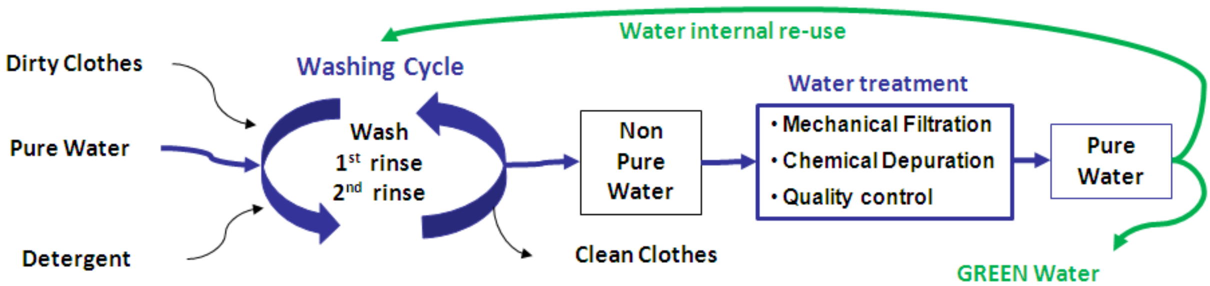


Figure 2: Research activity methodological approach

The final aim of the research activity discussed in this paper is to design a modular multi-system apparatus for water treatment to be integrated inside a washing machine. This apparatus will enable the filtration, depuration (i.e., purification) and quality control of washing water, to enable its re-use in successive cycles. The main benefit would be not only the reduction of the total amount of water needed (proportional to load amount), but also energy savings including hot water savings and water stored at room temperature (e.g.: 23°C) which is warmer than the temperature of water coming from the supply network (on average 15°C). Obviously, performance quality expected by users will have to be preserved.

The final results of this research activity will be a washing machine with an apparatus consisting of a storage tank, equipped with water quality control sensors, a water treatment device (based on bio-chemical and/or advanced oxidation processes), a filtering system, a re-circulating pump, additional valves and pipelines (Figure 3).[1]

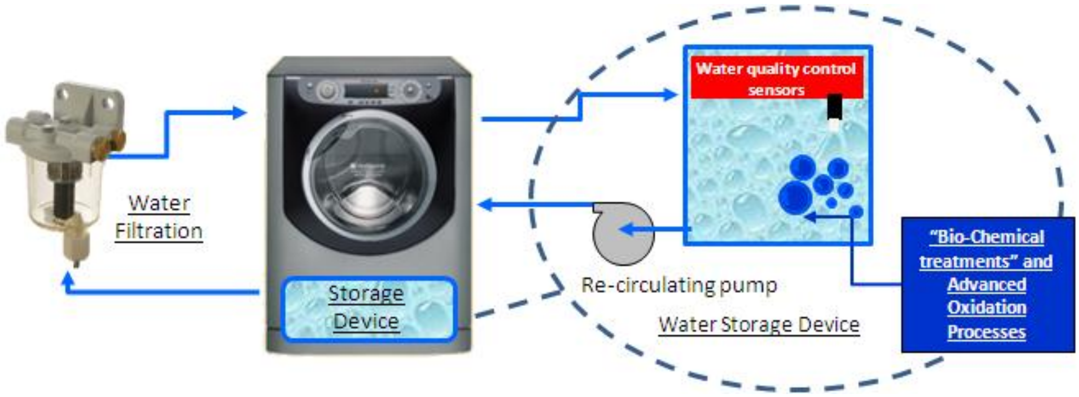


Figure 3: Washing machine with water treatment devices

Dedicated sensors will be developed to control water quality. Particularly, the research and the implementation will be addressed by innovative low-cost solid state sensors to analyze the quality of wash/drain water in terms of dissolved substances (such as coloring agents, detergents, dirt). Furthermore, a specific "safety period" will be evaluated and defined, to avoid bacteria proliferation issues, after which the stored water should be automatically unloaded. In the following sections (3.1 – 3.2 – 3.3), an overview of the implemented technologies is provided.

3.1 – Water storage and filtration methodological approaches

Storage: Regarding washing issues, household appliance manufactures generally aim to reduce water consumption and develop new products that integrate heated water, detergent and laundry during the wash phase, with easy removal of residual detergent, soils and wasted water during the one or two rinse phases. Water consumption in commercial washing machines can be reduced by using stored water from previous washing cycles [5]. Storage-reuse suffers from the problem of micro-bacterial presence and proliferation [6, 7]. The survival and distribution of microflora were analyzed using an Indesit Company washing machine production model (*Aqualtis*®) operated during washing machine cotton cycle at 60°C with a commercial liquid detergent.

Filtration: Products not related to household appliances are currently available to filter drain water by mechanically filtering suspended solids with an average granulometry from about 10 micron to 100 microns. These products are used for different applications. Membrane filtering systems operating with pressurized fluid (from 2 to 7 bar) have been considered in this research. Membranes are divided mainly into three categories depending on the material (e.g., metal, polymer and ceramic). If water has suspended solids with smaller granulometry it will be necessary to use chemical or inertial systems (i.e., flocculation, sedimentation, forced suspension). The removal of bacterial loads is

[1] Advanced Oxidation Processes refers to a set of chemical treatment procedures to remove organic and inorganic materials by oxidation. Contaminants are oxidized by four different reagents: ozone, hydrogen peroxide, oxygen, and air, in pre-programmed dosages, sequences, and combinations. These procedures may also be combined with UV irradiation and specific catalysts. Contaminant materials are converted into stable inorganic compounds such as water, carbon dioxide and salts, i.e. they undergo mineralization. AOP water purification reduces chemical contaminants and toxicity to such an extent that cleaned waste water may be resued or sent to conventional sewage treatment.

typically achieved by liquid oxidizing agents such as bleach, for controlling parameters like Biological Oxygen Demand (BOD).[2]

3.2 – Chemical water treatment methodological approach

To eliminate water pollutants, a possible approach may be the combination and application of physico-chemical and biological means. In this research, Advanced Oxidation Processes (AOPs) have been proposed to decompose pollutants with UV-peroxide, ozone, photocatalysis, electrokinetics, sonolysis, electron beam and γ radiolysis. AOP is effective in decomposing hazardous compounds in water [8, 9, 10]. All these methods are based on the generation and use of the hydroxyl radical as the primary oxidant for the degradation of organic pollutants. The $^{\bullet}OH$ radical initiates the decomposition of most organic compounds achieving, in some cases, their complete mineralization. Whenever necessary, its high standard efficiency can be further increased by an order of magnitude by titanium dioxide photo-catalysis. $^{\bullet}OH$ operates its oxidizing action by abstracting a hydrogen atom from the carbon chain or by accepting an electron (electron transfer), or by adding to a π system (bond breaking). Therefore a series of reactions are initiated, like peroxidation, fragmentation, further H abstraction, disproportionation, molecular growth, which may continue even after the initial action of OH is terminated. The choice of a particular AOP, besides considering the nature of waste water and energy requirements, should match with the ability to be scaled down, as it is in the case of domestic appliances, and with its rapidity of action. In section 4.2 the investigation of AOP treatments will be described, taking into account chemical processes dynamics main parameters, together with research project main objectives, such as waste water reuse.

3.3 – Water quality monitoring and sensing methodological approach

Water quality is an important environmental variable, as it affects human health and economic activities. A combination of factors, ranging from water scarcity, industrial plants automation, quality control and water efficiency/treatment, has necessitated the implementation and development of new water sensing technologies [11, 12]. Water quality monitoring in Europe is intended to control water pollution and enforce its saving, reuse and treatment. Modern water legislation in Europe pursues the target of sustainable planning and public participation by the Water Framework Directive (WFD) (2000/60/EC). Water quality monitoring using remote sensing technology regularly provides and updates both time and spatial distribution of water quality parameters, especially for the basins and channels of the drinking water. Remote sensing technology and distributed sensor networks are valuable tools for obtaining information on the parameters of water quality such as conductivity, turbidity, dissolved oxygen, dissolved organic carbon, temperature, pH, free chlorine, oxidation reduction potential (ORP), nitrates, nitrites, ammonia, biological micro-organisms, etc [13,14].
Accurate real-time detection based on distributed networks of solid-state sensors of chemical and biological contaminants is useful for planning and implementing mitigation measures to protect water supplies and to support green-economy [15,16]. These sensors are a great advantage in operational economics and for on-line and in-situ potential use in both drinking water security and water quality monitoring.
Among the water quality advanced transducers, the piezoelectric devices based on quartz substrates are miniaturized, robust, simple tools to measure some water parameters such as conductivity, viscosity and pH. Recent advances in bulk acoustic wave sensor platforms such as geometries of the lateral field excited (LFE) and the monolithic spiral coil acoustic transducer (MSCAT) are reviewed by J. F. Vetelino group [17,18]. These piezoelectric devices are coating-free and only one surface of the planar sensor is in contact to liquid sample. They are some advantages of the water quality devices to prevent aging (i.e., sensitive coating, metal electrodes) by resulting in a stable sensor signal and good accuracy. In this work, chemical analysis by instrumentation of the wastewater from a domestic appliance (clothes washing machine) has been performed to select one or more water quality parameters to be monitored in order to design a sensor-system based on planar piezoelectric device for controlling the continuous operations of the washing process. The methodology used for chemical analysis of the wastewater from a domestic appliance is described here. The wastewater (25-30 liters per washing) from a clothes washing machine by Indesit Company (standard test cycle [19]) has been

---

[2] Biological oxygen demand (BOD) is a measure of the amount of oxygen that is consumed by bacteria during the decomposition of organic matter.

collected in plastic vessels for successive chemical analysis. The water has been picked up at 6 different steps along washing cycle. The parameters of the water quality have been measured by a Multiparameteric probe (In-situ Inc, Model Troll 9000). Additionally, Italian standardized procedures (APAT, CNR-IRSA 5170 MAN 29/2003) based on analytical equipment have been used to measure the concentration of anionic surfactants (mg/l) regulated by the MBAS standard (Methylene Blue Active Substances assay).

4 – Laboratory testing procedures and set-up

This section describes the procedures used in the laboratories of research project partners during the investigation activity of the performances of each technological solution to be implemented. The targets were two-fold: (1) to obtain data on the performance of each research line in consistent and semi-controlled environments, (2) to compare testing procedures with current or developing standards and directives to come up with improved procedures. The research described in this paper is part of a three-year project (2009-2012) which is ongoing. These data will include initial suitability assessments of each technology for the household appliances industry. The results will provide important data for the next technical feasibility assessment and design of a dedicated system. Future research studies will use the Italian water quality standards [20] as the reference since no other standards are available for domestic appliances. The Italian standards define the chemical/physical constraints and methodology of analysis (in terms of limit values in surface water and sewerage), for water reuse and/or drainage mainly for industrial or civil fields.

4.1 – Storage and filtration experimental plans

The experimental plan consisted of two steps: (1) second rinse water chemical screening, and (2) microbiological analysis. In particular, the first step focused on finding the worst aqueous solution in terms of bacteria proliferation potential.

Chemical screening: The aim is to characterize and test the water resulting from a washing cotton cycle at 60˚C completed in about 2h and 30 minutes. The soiling, the load of cotton and the detergents have been selected according to [19 - Annex U] (respectively with 77% base powder with enzyme and foam inhibitor, 20% sodium perborate tetrahydrate, 3% bleach activator TAED). At each step, a sample was collected to measure pH, sediment solids, and suspended solids (Table 2 shows the details of the experimental campaign).

Table 2. Chemical screening experimental DoE on rinse water

ID	Branded Detergent	Detergent type	Detergent dosage(*)	Branded Softener	Softener dosage (*)	Branded Bleacher	Bleacher dosage (*)
1A	“A”	powder	normal	“M”	Double	---	----
1B	“A”	powder	normal	“N”	Normal	---	----
2A	“A”	powder	double	---	----	---	----
2B	“A”	powder	normal	---	----	---	----
3A	“B”	liquid	double	---	----	---	----
3B	“B”	liquid	normal	---	----	---	----
4A	“C” with softener	liquid	double	n.a.	n.a.	---	----
4B	“C” with softener	liquid	normal	n.a.	n.a.	---	----
5A	“A”	powder	normal	---	----	“Q”	double
5B	“A”	powder	normal	---	----	“Q”	normal
6A	“A”	powder	normal	---	----	“P”	double
6B	“A”	powder	normal	----	-----	“P”	Normal

(*): respect to the recommended quantity

The experimental work was then focussed on the analytical characterization of the sample of second rinse water for each cycle. COD, pH, sediment solids, suspended solids, BOD_{20} (biochemical oxygen demand after 20 days) were evaluated for bacteria proliferation potential.[3] Considering the data coming from the detergent screening (Table 2), it was decided to retry the same washing cycle using the liquid detergent with doubled dosage and doubled soil load (10 instead of 5 soil reference stripes added plus other 5 stripes containing only greasy oily) [19]. All the water expelled after the second rinse was collected for the subsequent bacteria cultivation.

Microbiological analysis: The analysis consisted in the evaluation of variance concentration on 5 different water samples all coming from the same second rinse during 20 days of warehousing by Thoma chamber lecture (1000 of magnitude) at 0,2,5,12,15 days along with oxygen uptake (OU) measurement.

Table 3. Microbiological screening experimental DoE on rinse water

ID	Number of tests	Stain strips (*)	Inoculation	Anti-microbial treatment
1	1 (Reference)	NO	NO	None
2	4 (for each inoculation)	YES	YES	None
3	4 (for each inoculation)	YES	YES	30’ with O3 gas flux
4	4 (for each inoculation)	YES	YES	colloidal nano-Ag powder (100 mg/solution)
5	4 (for each inoculation)	YES	YES	sodium hypochlorite (1,15%w/w)

(*): according to [19]

Each water sample consisted in 4 screen tests, inoculated each one with one of the following test strains: (1) Enterococcus faecium LMG 15709, (2) Mycobacetrium terrae LMG 10394, (3) Staphylococcus aureus LMG 8064, (4) Candida albicans MUCL 38887 in liquid suspension containing 1010 CFU/ml. The 5 water samples are described in Table 3.

Filtration: The last part of the work was devoted to building and testing a pre-prototype machine opportunely modified via hardware and software to allow storage and reuse of the second rinse water, plus a filtration device to treat water during the rinse operations.
The washing machine was implemented with a three-way valve after the drain pump ,connecting a filter cartridge holder. The filter was connected with washing tub to recirculate filtered water. The scheme of the entire new configuration is reported in Figure 4.

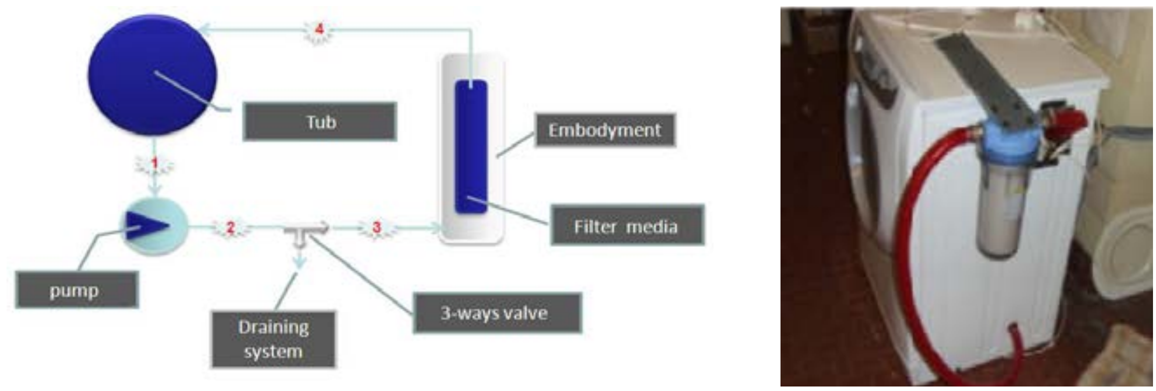


Figure 4: Scheme of the water filtration system and the working prototype with polymeric filter

Two different types of filters have been used: a polymeric one and a metallic one. The characteristics of each of them are reported below:

- Metallic: ruffle steel plate, 75micron mesh, 25cm length, 10 cm of diameter

[3] Chemical oxygen demand (COD) measures the amount of oxygen that is consumed by the water in the decomposition and oxidation processes, specifically the decomposition of organic matter and oxidation of inorganic matter, or chemicals.

- Polymeric: polypropylene non-wowen fibres, filtration degree 40 micron mesh, 25cm length, 10 cm of diameter.

The Cotton cycle used in the previous experiments was modified including water recirculation and filtration operations. Two washing cycles were performed and analyzed in terms of COD.

4.2 – Chemical water treatment experimental plan

As previously described in section 3.2, the investigation on AOPs treatment was carried out both on the physical-chemical side (process parameters of model systems) and on the industrial one (economical and technical implementation feasibility). Rinse cycle water samples were exposed to three types of energy: UV light, ultrasonic waves, and ionizing radiation (γ-rays). These technologies reduce the toxicity of hazardous organics, without producing secondary pollution or transferring the pollution to another media. Furthermore, these technologies can be designed in conjunction with established treatment areas inside the washing machine.

The impact of the following parameters were evaluated: total dose of energy, frequency of exposure, gas atmosphere (Air, O_2, N_2O), and added compounds (H_2O_2, TiO_2) as oxidation enhancers. Sample changes were monitored through UV-vis spectrometry, TOC, BOD5, and eco-toxicity by the luminescent bacteria method.

Specifically, standard cotton containing standard stripes were washed employing three types of detergent: a branded powder (BP) (recommended dosage), a branded liquid (BL) (recommended dosage), a standard detergent (SD) (according to [19]). The water wasted by each step of the washing cycle (washing, first rinsing, second rinsing) was collected and treated by the three AOP methods previously mentioned (UV/H2O2 system, ultrasound cavitation (US), γ-rays,). Energy exposures were performed by a Nordion 220 gamma-cell, a Rayonet reactor RPR-100 constituted by 16 UV lamps (Sylvania 8W, 256 nm), and a Transsonic 95/HL Elma tank (720W, 35 kHz), respectively. The treatments applied to the rinse cycle water samples were the following:

- UV/H2O2: 250 ml of waste water from each step were irradiated from the top of the open Pyrex pans for 1 hour. H2O2 concentration was 10 mM (Figure 5);
- US: 2.5 l of waste water from each step were sonicated directly in the US tank for 1 hour;
- Gamma-rays: 250 ml of waste water from each step were irradiated for 18 hours in polythene vials with a dose of 10.3 kGy.

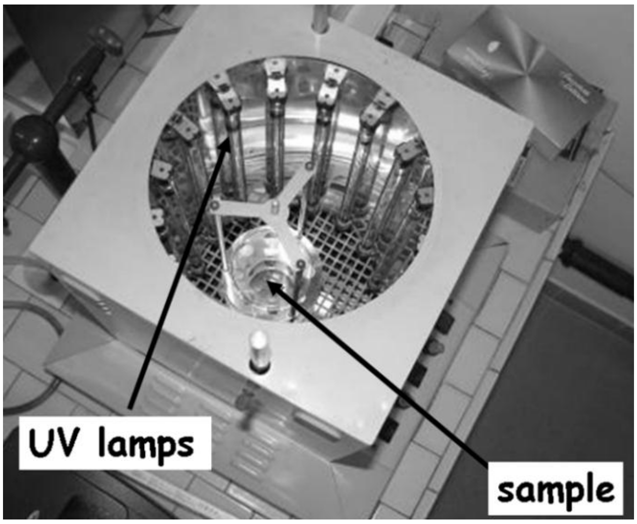


Figure 5. Typical UV irradiation set up seen from the top.

4.3 – Water quality monitoring and sensing experimental plan

A quartz crystal microbalance (QCM) with two metal electrodes on both sides is properly arranged. A circular AT-cut quartz crystal is used to electrically excite the resonant thickness shear mode (TSM) in the crystal. The frequency of the QCM device employed is 10 MHz. The piezoelectric transducer is inserted in a close loop with an amplifier to implement a frequency oscillator. The sensor output signal is the resonant frequency depending on change in the conductivity of the test water sample. Electronics is integrated for oscillator.

The water samples picked up from the domestic appliance (clothes washing machine) have been analyzed with a double instrumental test. The first is a Multi-parametric probe (In-situ Inc, Model Troll 9000), equipped with different sensing probes to measure various water quality parameters such as conductivity, pH, temperature, turbidity, oxido-reduction potential (ORP), while the second is an analytical equipment (spectrophotometer) according to the standardized procedure MBAS to measure the concentration of the anionic surfactants dispersed in the wastewater used for clothes cleaning with different types (powder or liquid) of detergent.

5 – Results assessment

Results are presented for the following three experimental campaigns: 1) storage and filtration, 2) chemical water treatment, and 3) water quality monitoring and sensing.

5.1 – Storage and filtration: results and discussion

Microbiology: The BOD (Biochemical Oxygen Demand) tests showed (Figure 6) that in a period of 5 days the oxygen demand for the inoculated (C curve) and white samples (B curve) underwent a linear increment with a linear coefficient of 46g/l and 27 g/l respectively. The oxygen consumption remained constant from the 5th to the 20th day, maintaining an oxygen demand constant ratio of 3 (300 mg/l and about 100mg/l). The Thoma chamber lecture evidenced an exponential behavior for CFU (Colony-Forming Unit) values (Figure 7), but it was detected an initial diminution of CFU for the inoculated samples (C curve), and a subsequent exponential curve having a growth rate of 0,06 day^{-1}. However, the 20th day value was close to the initial one for both cases. By observing the global CFU values (Figure 8), the water treatment results were effective: the efficiency of hypochlorite (Am2 curve) depends, as expected, on its quantity; the best antibacterial agent was found to be the nano-colloidal Ag (Ag curve), while the ozone treatment (O3 curve) showed intermediate results. All the exponential digression curves evidenced a similar growth velocity.

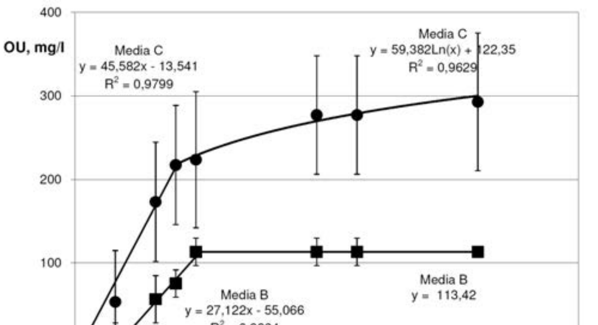


Figure 6: BOD values behaviour vs. time (C:inoculated samples; B: white sample)

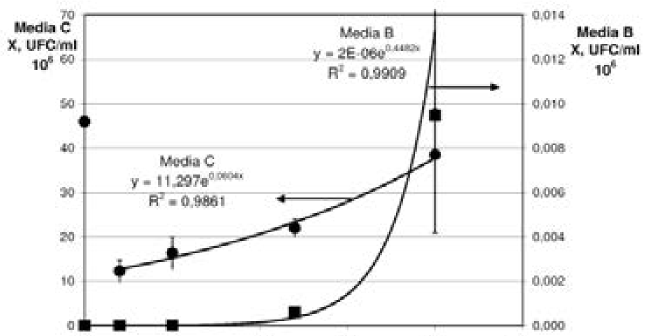


Figure 7: CFU values behaviour vs. time (C:inoculated samples; B: white sample)

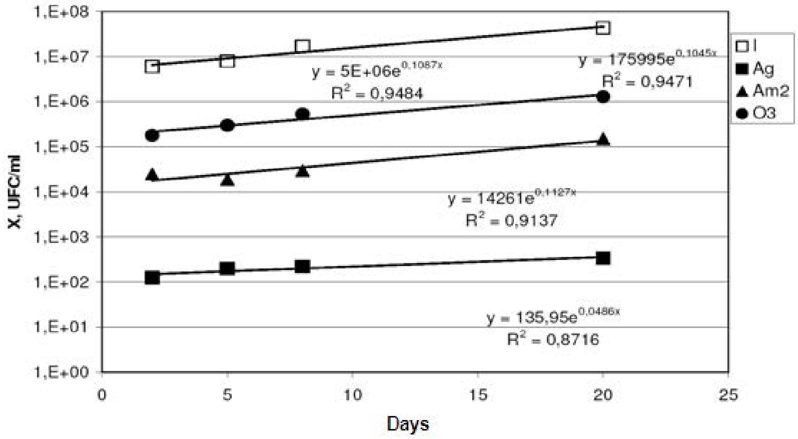


Figure 8: Global CFU behaviour vs. time with no treatment (□I) and with ■ nano-colloidal Ag, ▲ hypochlorite, ● ozone treatments

Chemical analysis: In Table 4 all data are collected to describe water conditions in each cycle step (washing, 1st rinse, 2nd rinse). A relevant consideration comes by observing the pH decreasing at each step of the cycle by one order of magnitude, suggesting that detergent presence (along with the soil-detergent micelles) decreases drastically over washing cycle, reaching a minimum in the 2nd rinse water sample (pH=8). Partially aligned to the pH values, the COD, the suspended solids and sediment solids indicate the presence of soil (COD and sediment solids) or micelle soil-detergent (suspend solids) decreases dramatically from the washing phase until the 2nd rinse. This evidence supports the hypothesis of safely reusing final rinse water.

Table 4: Water samples over cycle description

Items/cycle step	Washing	1st rinse	2nd rinse
pH	9.9	9	8
COD [mg/l]	3200	500	120
Sediment solids [g/l]	2.1	1.7	1
Suspended solid [ml/l]	0.51	0.15	0.028

The detergent screening further clarifies the role that different detergent types could have towards the soil and detergent presence in the 2nd rinse water. Liquid detergent with a double dosage has furnished the highest COD value, similar to COD value of first rinse water with standard dosage. All the monitored parameters reported in Table 5 provide evidence that suspended solids values are aligned to COD behaviour, and that chemical activity after 20 days was detected only when liquid detergent has been used. These data can be explained with the different chemical composition between powder and liquid detergent, the former having percarbonate working as strong oxidant, absent in the latter.

The COD values achieved for the three samples obtained the activation of the filtration unit was compared with samples obtained from a washing cycle performed using recycled water coming from a 2nd rinse. All data are reported in Figure 9. The COD values of a standard cycle have been reported as reference.

The graph illustrates how the polymeric filter reduces COD from 4000 mg/l of O_2 consumption to 3000mg/l. The other two cycles gave values comparable to reference values. Even if slightly more efficient filtration of narrow meshes is used, the unstable nature of micelles in terms of size should explain wider improvement in water quality by filtration. The COD values measured on samples from washing cycle performed with the 2nd rinse water reuse appears to be substantially aligned with values achieved after a standard cycle. This finding motivates development of water recycling design in this direction.

Table 5: Detergent screening main monitored parameters

ID	COD [mgO_2/l]	pH	BOD20 [mgO_2/l]	Sediment solids [mg/l]	Suspended solid [ml/l]
1A	30	7,13	0	11	0,1
1B	29	7,61	0	13	0.9
2A	183	7,62	0	22	0,1
2B	119	7,3	0	13	0,1
3A	497	6,98	10	60	0,5
3B	164	7,16	10	23	0,1
4A	81	6,89	15	8	0,1
4B	102	6,07	15	12	0,1
5A	154	7,48	20	12	0,1
5B	158	8,2	20	11	0,1
6A	60	10,07	0	2	0,1
6B	127	8,41	0	5	0,1

The performance registered after the last experimental phase indicates that the hypothesis of filtration, despite being heavy in terms of implementation, is not completely justified by the experimental evidence in terms of advantages. On the contrary, the recycling and reuse hypothesis could give promising performance especially if coupled to appropriate storage tank design.

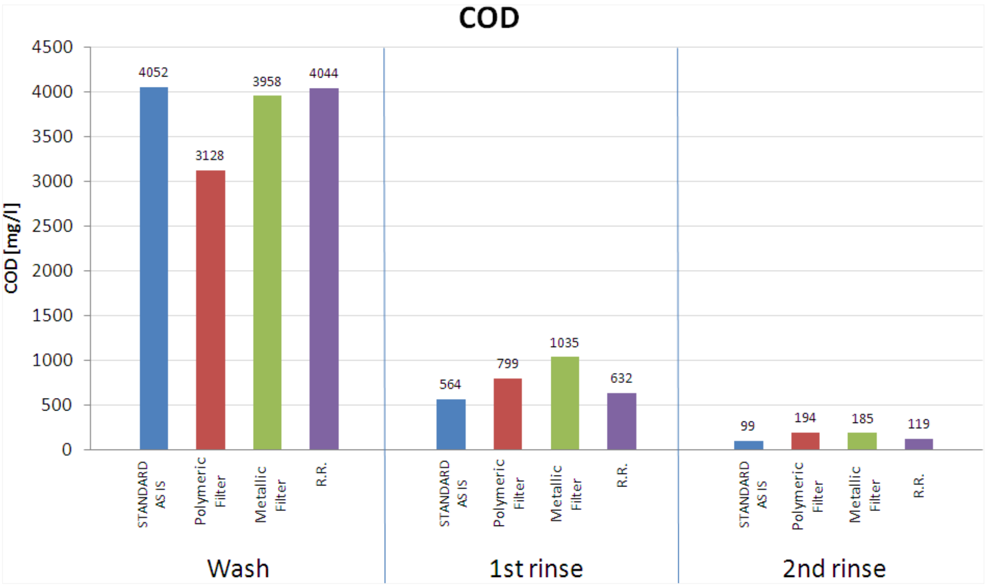


Figure 9: COD values for different water mechanical treatments

5.2 – Chemical water treatment: results and discussion

The analyses monitored changes of pH, conductivity (mS/cm), COD (O2 mg/L), and concentration of ionic and anionic detergents (mg/L) after each treatment (see 4.2). Variations below 20% were considered not significant due to typical sensitivity of the methylene blue method, the standard method used for the determination of anionic surfactants. Both pH and conductivity do not show significant changes over all experiments, in particular the samples maintained their neutral-alkaline character. More details about COD and AS/NIS surfactant reduction in dependence of the system used are given as follows.

- *COD*: a) γ-rays generally induce a mild COD reduction at the edge of the sensitivity level; b) UV/H2O2 produces around 90% COD reduction only for the second step (first rinsing) with branded liquid and standard type detergents (BL and SD, respectively): c) with US COD is reduced by 25-38% only in the rinsing cycles and for the SD type detergent.

- *AS (Anionic Surfactants):* a) γ-rays degrade over 90% of AS belonging to the branded powder and standard detergents (BP and SD, respectively) and contained in the first and second rinsing cycles; b) for UV/H2O2 the degradation effectiveness is similar to that of γ-rays; c) US do not have significant effects except in the case of SD.
- *NIS (Nonionic Surfactants)*: a) γ-rays are moderately effective in the degradation of NIS, achieving the best result (62%) in the second rinsing when using the branded powder detergent (BP); b) UV/H2O2 effectiveness seems slightly weaker than that of γ-rays, but always in the range 40-60% degradation particularly for the second rinsing; c) with US, a limited degradation (up to 45%) of NIS are obtained only using BP and BL detergents. In the other cases changes are not significant.

These results are schematically represented in Table 6.

The provisional conclusions to be drawn from the above observations are that rinsing water can be effectively remediated by the Advanced Oxidation Processes, by reducing substantially COD and the concentration of surfactants. Some sources of energy (γ-rays and UV) show to be more effective than others (US), although the US method likely needs to be further tuned in search of the critical frequency that triggers water cavitation process.

Table 6. COD % reduction, Anionic (AS) and Nonionic Surfactants (NIS) degradation

Detergent Dosage	WASHING Phase	γ-rays			UV + H_2O_2			US		
		COD	AS	NIS	COD	AS	NIS	COD	AS	NIS
BP 35g	1°	(**)		(**)	(**)		(**)	(**)	(**)	(**)
	2°	(**)	95		(**)	98	(**)	(**)	(**)	(**)
	3°	(**)		62	(**)		53	(**)	(**)	45
BL 120 ml	1°	(**)			(**)	(**)		(**)	(**)	35
	2°	(**)			89	52		(**)	(**)	
	3°	29	51	59	(**)		64	(**)	(**)	
SD 125 g	1°	(**)	(**)		(**)	(**)	(**)	(**)	(**)	(**)
	2°	25			94		(**)	38	29	(**)
	3°	(**)	91	49	(**)	93	43		(**)	(**)

(**) negligible; 20-40%; 40-80% >80%

5.3 – Water quality monitoring and sensing: results and discussion

The results achieved, for the wastewater samples by using the Multi-parametric probe for two sets of wastewater from clothes washed with standardized *powder* detergent [19] and branded *liquid*, are shown in Table 7 and Table 8, respectively. The cycle of the clothes washing machine was set as *Cotton 60°C* (see 4.2).

These results demonstrate that both conductivity and turbidity decrease with the repeated cleaning of the clothes in the appliance; while the ORP increases with cleaning process. However, the *washing water* exhibits the maximum value of conductivity and turbidity for both used detergents (standardized powder and commercial liquid). This high value of conductivity and turbidity is caused by the first wastewater of the washed dirty clothes containing high amount of anionic surfactants and particulate matter. The measurement tests on wastewater samples collected from the appliance (*Cotton cycle* working at a temperature of 60°C) have been carried out at room-temperature after about two-hours in order to cool the wastewater. This is necessary to avoid the influence of the temperature on measured water quality parameters (i.e., conductivity, turbidity, ORP, etc.).

Table 7. Washing machine wastewater characterisation using standard detergent/load [19].

Water Samples	pH	Conduct. (μS/cm)	Turbidity (NTU)	t (°C)	ORP (mV)
supply net water	6.52	712	-0.2	14.5	207
washing water	7.33	3377	1827	14.2	169
first-cleaning water	5.71	2153	413	15.0	206
second-cleaning water	6.65	1053	136	15.6	236

third-cleaning water	6.05	842	42.5	16.0	270
extra-cleaning water	5.87	752	24.4	16.1	291

Table 8. Washing machine wastewater characterisation using branded liquid detergent.

Water Samples	pH	Conduct. (μS/cm)	Turbidity (NTU)	t (°C)	ORP (mV)
supply net water	7.44	730	-0.5	17.2	225
washing water	11.46	1022	578	25.1	174
first-cleaning water	8.63	840	71	21.7	254
second-cleaning water	7.62	810	37	20.0	361
third-cleaning water	7.16	773	39	18.3	409
extra-cleaning water	9.43	691	1	17.0	408

Finally, the conductivity and turbidity could be selected as indicator to retrieve the state of the water quality of the appliance waste in order to assess the possibility of the reuse of water for next washing cycles. In particular, the conductivity can be measured by a low-cost piezoelectric sensor for on-line process control in the appliance.

Hence, the correlation between conductivity and concentration of anionic surfactants in the wastewater has been also investigated to corroborate the hypothesis that conductivity is a significant parameter to assess water quality in the appliance waste. Indeed, controlled amount of standardized powder has been intentionally added to water and MBAS (methylene blue active substances) procedure has been applied to quantify the anionic surfactants. Results are shown in Table 9, showing that the conductivity and the concentration of anionic surfactants decrease with the decreasing amount of detergent added to water. This result evidences that conductivity and concentration of anionic surfactants are strictly correlated.

These results demonstrate that the conductivity can be an effective indicator to retrieve the state of the water quality in the appliance. Therefore, a cost-effective piezoelectric sensor-system has been designed as pre-prototype for on-line measurements in the washing cycle of the domestic appliance. The performances of this sensor-system are now under investigation.

Table 9. Water with branded detergent, measured with MBAS assay.

Water Samples	pH	Conduct. (μS/cm)	ORP (mV)	Turbidit y (NTU)	Concentr. of anionic surfactant (mg/l)	Temp. (°C)
supply net water	9.7	728	920	0.8	0	25
Water + 0.5 wt.% Det.	9.9	837	664	289	233	25
Water + 0.25 wt.% Det.	9.85	778	668	150	-	25
Water + 0.125 wt.% Det.	9.8	744	695	68	81	25
Water + 0.06 wt.% Det.	9.78	742	720	31.7	60	25
Water + 0.03 wt.% Det.	9.6	725	737	15.9	24	25
Water + 0.002 wt.% Det.	9.5	713	775	1.3	1.25	25
Water + 0.0005 wt.% Det.	9.32	718	790	0.7	0.39	25

6 – Conclusions

The following aspects have been investigated in order to release a technical pre-feasibility for wastewater reuse and treatment in domestic washing machines: water reuse as-is, water bacteria proliferation in the storage tank, mechanical filtration effectiveness and AOP treatments to reduce pollution in the water. Preliminary tests have shown that bacteria proliferation on 2^{nd} rinse stored water decreases using bactericide based methods, such as nano-colloid Ag, ozone (insufflated directly in water) and hypochlorite (added on water solution). Water filtration tests showed positive results with polymeric filter based on observations of COD decreasing in washing water . AOP-based methodologies could be also effective in COD reduction and in degradation of anionic surfactants and nonionic surfactants, as demonstrated by the experimental campaign. Furthermore ozone and UV treatments could be also applied as anti-microbial agents. The research activity carried out on water sensing has demonstrated that correctly monitoring the conductivity values of the water could be the right approach to keep it under control in terms of its quality. The measured COD value and its correlation to conductivity could enable the implementation of different water reuse algorithms (cycles) ranging from total reuse of wastewater until its mixing with the supply net one. All the technologies have been tested separately demonstrating the possibility to apply a modular approach for the final implementation. Results for clothes washers can be applied to other appliances such as dishwashers. These results provide important data for designing a dedicated "green washing" system..

References

[1] www.oecd.org/environment/households

[2] Pakula, C., Electricity and water consumption for laundry washing by washing machine worldwide, Energy Efficiency, Vol. 3 (4), pp. 365-382, DOI: 10.1007/s12053-009-9072-8.

[3] George, K.L., Horizontal-axis clothes washer market poised for expansion, E Source, Inc., Boulder, CO (United States), DN: Publication No. TU-94-6; PBD: 1994.

[4] http://www.thomsoninnovation.com/

[5] Scamehorn, J. F., Tucker, E. E., Gecol, H., Komesvarakul, N., Serventi, L. K., Raney, K. H. and Capps, S. F., Industrial Home Laundry Closed Loop Cleaning Process, Journal of Surfactant Detergent (2007), Vol. 10, pp. 287–299, DOI 10.1007/s11743-007-1044-4

[6] Fujioka K., Kozone I., Saito M., Matsuoka H., (2006). Rapid evaluation of the efficacy of microbial cell removal from fabrics. J Ind Microbiol Biotechnol., 33, 995-1002

[7] Fijan S., Koren S., Cencič A., Šostar-Turk S., Antimicrobial disinfection effect of a laundering procedure for hospital textiles against various indicator bacteria and fungi using different substrates for simulating human excrements. Diagnostic Microbiology and Infectious Disease, 57, 251-257

[8] Legrini, O., Oliveros, E., Braun, A.M., Photochemical process for water treatment. Chem. Rev., 1993, 93, p. 671.

[9] Kamat, P.V., Meisel, D., Nanoparticles in advanced oxidation processes. Current Opinion in Colloid and Interface Science, 2002, 7, p. 282.

[10] Pera-Titus, M., Garcia-Molina, V., Banos, M.A., Gimenez, J., Esplugas, S., Degradation of chlorophenols by means of advanced oxidation processes: a general review, Appl. Catal. B. Environment, 2004, 47, p. 219.

[11] Q. Chen, Y. Zhang, M. Hallikainen, Helsinki University of Technology, Whitepaper on Water Quality Monitoring using Remote Sensing in Support of the EU Water Framework, (www. idswater.com).

[12] United States Environmental Protection Agency (EPA) Report 600/R, Distribution System Water Quality Monitoring: Sensor Technology Evaluation Methodology and Results, October 2009.

[13] G. Mancino, A. Nolè, V. Urbano, M. Amato, A. Ferrara, Assessing water quality by remote sensing in small lakes: the case study of Monticchio lakes in southern Italy, iForest 2 (2009) 154-161.

[14] N. Usali, M. H. Ismail, Use of remote sensing and GIS in monitoring water quality, Journal of Sustainable Development 3(3) (2010) 228-238.

[15] Y. Jeffrey Yang R. C. Haught, J. A. Goodrich, Real-time contaminant detection and classification in a drinking water pipe using conventional water quality sensors: techniques and experimental results, Journal of Environmental Management 90 (2009) 2494-2506.

[16] H. B. Glasgow, J. M. Burkholder, R. E. Reed, A. J. Lewitus, J. E. Kleinman, Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies, Journal of Experimental Marine Biology and Ecology 300 (2004) 409-448.

[17] D. F. McCann, L. A. French Jr, M. S. Wark, J. F. Vetelino, Recent advances in lateral field excited and monolithic spiral coil acoustic transduction bulk acoustic wave sensor platforms, Measurements Science and Technology 20 (2009) 124001.

[18] D. F. McCann, J. M. McGann, J. M. Parks, D. J. Frankel, M. Pereira da Cunha, J. F. Vetelino, A Lateral-Field-Exicited LiTaO3 High-Frequency Bulk Acoustic Wave Sensor, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 56(4) (2009) 779-787.

[19] EN 60456: Clothes Washing Machines for Household Use - Methods for Measuring the Performance.

[20] D. Lgs 152/06, Tabella 3 – Valori limiti di emissione in acque superficiali e in fognatura.

Super Efficient Coffee Machines – Best Available Technology (BAT) and Market Transformation

Barbara Josephy, Eric Bush, Jürg Nipkow, Adelmo Pilone

Topten International Services (Paris, France), Swiss Agency for Efficient Energy Use S.A.F.E. (Zurich, Switzerland), Philips Saeco (Bologna, Italy)

Abstract

The stock of coffee machines in the European Union is estimated to be 100 million units, consuming 17'000 million kWh per year and causing electricity costs of about 2'500 Mio Euro (according to estimations by Topten). Roughly 20 million coffee machines are annually sold in Europe. For comfort and quality reasons, the trend goes towards espresso machines (fully automatic machines, portioned machines with high pressure) and filter pad machines; by now those machines account for about 45% of total sales, while the rest are mainly traditional drip-filter machines.

On account of the high energy saving potentials, manufacturers have implemented various efforts to increase the energy efficiency of coffee machines in the past few years. Energy efficiency particularly was enhanced with measures such as auto-power-down, better insulation of hot parts and low or zero standby consumption.

One striking development towards super efficient coffee machines is the application of flow-type heaters. Owing to the introduction of this technology by some innovative manufacturers these types of coffee machines represent the current best available technology (BAT).

This paper discusses the energy saving technology of flow-type heater for coffee machines, it gives an overview of the current state of the IEC 60661 standard (update in progress) and the EU Eco-design process (Lot 25) and it presents policy measures on European Minimum Energy Performance Standards MEPS and a labelling directive.

Introduction

For many people drinking coffee is part of their lifestyle. The range of the different coffee beverages is broad: in Europe well known are filter-coffee, espresso, cappuccino and latte macchiato.

The coffee beverages and the consumer preferences of coffee drinking habits are various and so are the preparation methods. Among the coffee machines with electricity supply, drip-filter coffee machines are still widespread in Europe. But for comfort and quality reasons, the trend clearly goes towards fully automatic machines and portioned capsule machines.

Conventional machines among these comfort products however account for large energy losses in particular in the ready mode to keep the temperature in the boiler or thermo-block permanently on 85°C to 90°C. Their keeping warm function may consume up to 170 kWh per year, depending on user's switching off practice. Never switching off would double this value. 170 kWh exceeds the annual energy consumption of a small A++-refrigerator, 75 kWh equals the consumption of an A-class oven used twice a week. The key parameters that strongly enhance the energy efficiency of coffee machines thus are auto-power-down, better insulation of hot parts, reduction of the thermal capacity of the heating unit, "energy saving mode", reduced or zero standby consumption and low amount of water to be heated for hygienic and quality purposes.

In the framework of the Eco-design Directive, the preparatory study on "non-tertiary" (i.e. for household use) coffee machines DG TREN Lot 25 is being carried out by BIO Intelligence Service (Paris) for the European Commission. It is attended by various stakeholders e.g. the European Committee of Domestic Equipment Manufacturers CECED, manufacturers, Topten (an international online search tool which presents the most energy efficient products such as household appliances, office equipment, consumer electronics, building components, lamps and cars, for more information see [1], [2]), the Swiss Agency for Efficient Energy Use S.A.F.E., the European Environmental Citizens Organisation for Standardisation ECOS and Oeko-Institute.

Leading initiatives to push the market introduction of high efficient coffee machines since many years are taken by Topten and S.A.F.E..

Types of Coffee Machines

Coffee machines with electricity supply can be categorized according to their pressure: machines with high pressure (> 8 bar), low pressure (< 8 bar) and no pressure (see Table 1 and Figure 1). For the preparation of a real "espresso" 15 bar are optimal. Therefore, machines with more than 8 bar are synonymously called "espresso machines". Coffee prepared with low or no pressure tastes more like drip-filter-coffee.

Table 1. Types of coffee machines.

Type	Pressure	Quality of Coffee	Synonym
Fully automatic machines	High	Espresso	Espresso machine
Portioned machines: Capsule machines	High	Espresso	Espresso machine
	Low (e.g. Tassimo)	Drip-filter-like	----
Portioned machines: Pad machines	Low	Drip-filter-like	----
Machines with piston lever	High	Espresso	Espresso machine
Drip-filter machines	No pressure	Drip-filter-like	----
Combi machines (Piston lever/Drip-filter)	High/Low	Espresso/Drip-filter-like	----

Figure 1. Types of coffee machines.

Stock, Sales and Market Trends of Coffee Machines

The stock of coffee machines in Europe is estimated at 100 million units (according to Topten). As shown in Table 2, annually more than 18 million coffee machines are sold in Europe [3].

Traditional drip-filter machines still have the highest market share (approx. 55%), followed by the portioned machines for pads (approx. 20%).

Espresso machines together with portioned machines for pads have a market share of 43% and an actual growth of 6.9%.

There is a considerable trend towards fully automatic machines (+5.5%) and an extremely strong trend towards espresso portioned machines (+43.1%), while low-comfort machines are losing market share (machines with piston lever, machines with filter-coffee quality such as portioned machines for pads, and the rare combi machines).

Table 2. Sales of coffee machines in 2006 and 2007.

Sales of Coffee Machines (in 1'000)	**2006**	**2007**	**Increase**
Fully automatic machines (Espresso machines)	824	870	5.5%
Portioned machines for capsules (Espresso machines)	1'647	2'356	43.1%
Portioned machines for pads	3'546	3'410	-3.8%
Machines with piston lever (Espresso machines)	1'358	1'246	-8.2%
Drip-filter machines	10'076	10'072	0.0%
Combi machines	312	284	-8.9%
All coffee machines	17'763	18'238	2.7%
All espresso machines and portioned machines for pads	**7'375**	**7'882**	**6.9%**

Source: GfK Group data of 18 European countries [3]:
AT, BE, CH, DE, FR, GB, ES, IT, NL, PT, SE, DK, FI, GR, PL, HU, CR, SR.

Energy Using Functions of Coffee Machines

The most energy using function of coffee machines is the permanently keeping hot of the water at 85°C to 90°C and strongly depends on the heating unit. Further energy using functions are the production of a cup of coffee, standby and electric motors, pumps and magnet valves (see also [4]).

Heating units: Boilers, Thermo-blocks and Flow-type Heaters

Due to high power rating (about 1'000 to 1'500 W) and considerable active time the heating unit claims the largest share of coffee machines' energy consumption. Most heating units do not only heat up cold water, but also keep it hot or keep a jug hot (drip-filter machines) as long as they are supplied with electricity.

Three types of heating units are common in coffee machines (see Figure 2): boilers (containing several hundred ml of water), thermo-blocks (containing 10 to 20 ml of water, but several hundred grams of aluminium) and flow-type heaters (containing about 10 ml of water). Their material contents and resulting thermal capacity at a temperature difference of 70°C (ambient 20°C, coffee production 90°C) are shown in Table 3.

Figure 2. Heating units of coffee machines: Boiler (left), thermo-block (middle) and flow-type heater (right). Source: Topten

Table 3. Properties of heating units for coffee machines.

Type	Boiler	Thermo-block	Flow-type Heater
Water	200 g	10 g	10 g
Metal	400 g	650 g	120 g
Thermal capacity at ∆T = 70°C	22 Wh	12 Wh	3 Wh

Production of a Cup of Coffee

The amount of energy physically needed to heat up water for an average cup (80 g) is 6.5 Wh (at a temperature difference of ∆T = 70°C). Measured values according to Topten-measurements and FEA/CECED-forms range from 8.1 to 14.7 Wh (see Figure 3). They comprise also the energy for pump and grinder, if existing (in the range of 1 Wh each). These values are significantly lower than the heating up energy of typical boilers. Values below 10 Wh signify good efficiency.

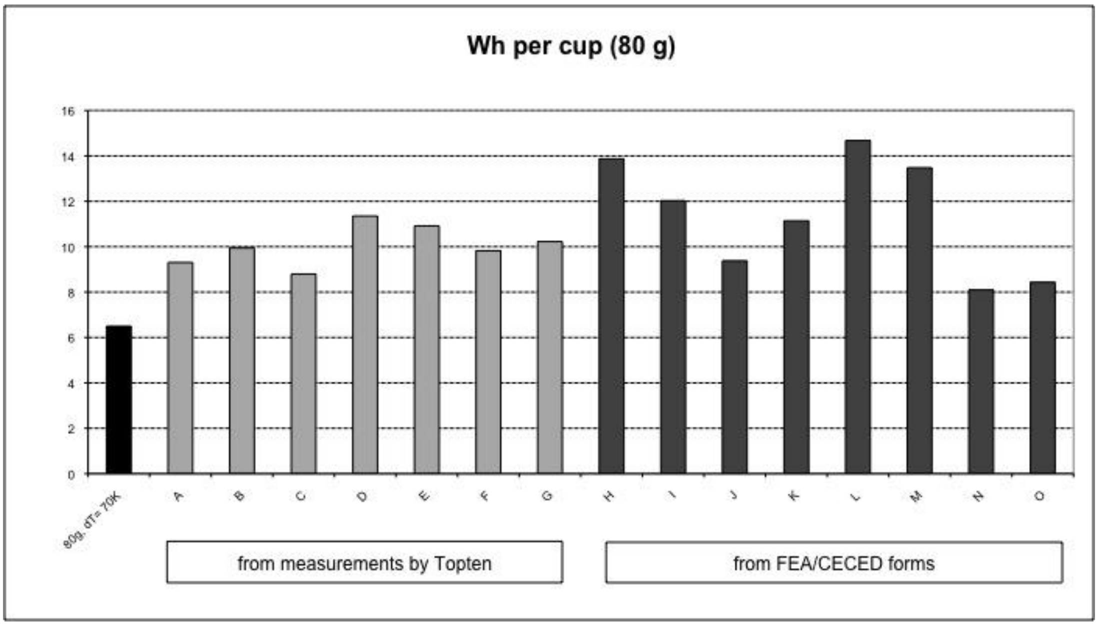


Figure 3. Energy needed for the production of a cup of coffee (80 g, in Wh).
Source: Topten

Standby

Appliances with automatic functions such as a coffee brewing process, a timer to switch on at pre-set times or an auto-power-down function need a power supply unit to generate the low DC-voltages for the electronics. Power consumption of older electronic power supplies was up to 5 W, while efficient new ones consume less than 1 W, e.g. 0.3 W. Standby duration depends on the active state duration, typically it is about 7’000 hrs per year, resulting in 2 to 7 kWh per year. For high efficient coffee machines, this is a small but not quite negligible value. For coffee machines, zero standby is possible (see below).

Electric Motors, Pumps and Magnet Valves

Motors are used for grinding and automatic brewing units, pumps for all coffee machines except drip-filter machines, and electric valves for special process steps. These units may have considerable power ratings of e.g. 20 to 100 W, but their switched-on time is normally very short, e.g. some seconds to one minute. Therefore, their consumption share is very low and no specific efficiency measures are taken.

Measures to Reduce the Energy Consumption of Coffee Machines

The importance of the energy consumption during the use phase for life cycle eco-balance is shown by several studies (e.g. [5], [6]).

Conventional fully automatic and portioned machines account for large energy losses in particular in the ready mode to keep the temperature of the water permanently on 85°C to 90°C.

Measures that strongly enhance the energy efficiency of coffee machines are the availability of an auto-power-down and a short delay time, insulation of hot parts, reduction of the thermal capacity of the heating unit; "energy saving mode", reduced or zero standby consumption and low amount of water to be heated for hygienic and quality purposes (see also [4]).

Availability of an Auto-Power-Down and Short Delay Time

An auto-power-down function is the first and simplest measure to abbreviate the duration of the keeping hot state and thus to reduce the high energy consumption of the ready mode (keeping hot of the water). However, the duration of the delay time, or in other words, the time until the coffee machine switches from the ready mode into standby mode is important: the shorter the delay time the greater the impact of this feature.

New water heater units that are designed as flow-type heaters do not need auto-power-down, as they are activated only for coffee brewing and switched off immediately when the coffee production is finished (see below).

Insulation of Hot Parts

Thermal losses of heaters are substantially lowered by (even thin) insulation of the hot parts of coffee machines such as thermo-blocks and water heaters of any kind. The insulation prevents the cooling effect of air ventilating the hot parts immediately. Even with flow-type heaters a small efficiency gain by insulation is to be expected.

A very efficient type of insulation can be implemented for drip-filter machines: if the coffee is stored in a thermos jug (with vacuum insulation), no energy in form of electricity is needed to keep the coffee at the right temperature. This reduces strongly the energy consumption during the coffee period, but its value depends on the definition of the coffee period (see below).

Reduction of the Thermal Capacity of the Heating Unit

Reducing the thermal capacity of parts to be heated up is a further effective measure to reduce energy consumption. The smaller the thermal capacity the less "heating up"-energy has to be supplied.

A striking development towards super efficient coffee machines is the application of flow-type heaters. They have the lowest thermal capacity (due to their very small thermal mass) and thus are the most efficient water heaters for coffee machines. Coffee machines with flow-type heaters do not need auto-power-down and have no ready mode losses, as they are activated only for coffee brewing and switched off immediately when the coffee production is finished. Heat losses during the brewing process are also low because of their little water content and thermal capacity. Problems of the first brew being of minor quality because of too low water temperature can be solved by discarding the first few millilitres leaving the heater. Flow-type heaters need a sophisticated control of heating energy and pump to reach the desired water temperature very quickly but avoid overheating.

The flow-type heater shows a small non-insulated surface (see Figure 2). The huge energy saving potential compared to boilers and thermo-blocks is mainly due to the fact that it is heated only for 1 to 2 minutes whenever a cup of coffee is produced.

"Energy Saving Mode"

Some coffee machines have an "energy saving mode" or "eco-mode" which is factory set or can be programmed in the menu. This mode lowers the temperature of the heating element after a certain time (e.g. 5 minutes), from standard 90°C to about 60°C (e.g.). The coffee machine then is no longer in a real ready mode, but requires some heating time before dispensing coffee. It takes less time however than heating up from the cold state. This type of "energy saving mode" allows good energy efficiency figures also with somewhat longer auto-power-down delay times. A question of technical terms may arise: the "low-temperature eco-mode" is nor a standby mode nor a real ready mode. This should be adequately treated by a measuring method.

Reduced or Zero Standby Consumption

The shorter the delay time of the auto-power-down the longer the machine remains in standby. The allowed energy consumption in standby is regulated by the Eco-design Regulation for standby and off mode consumption [7]. As the use of a coffee machine requires pressing a button or another manipulation anyway, there is no need for a standby function as e.g. for TV sets, which are to be activated by a remote control. Therefore zero standby does not cause any technical problems for coffee machines and can be easily implemented. As most coffee machines afford an electronic control and soft switches, the extra costs of zero standby are small.

Low Amount of Water to be Heated for Hygienic and Quality Purposes

Most coffee machines heat up certain quantities of water for rinsing purposes when switched on or off, or they discard a small amount of coffee at the beginning of the brewing process, which might be not hot enough or not of sufficient quality. Decalcification and (automatic) cleaning also is an energy (and resources including chemicals) consuming aspect in the life cycle of coffee machines. There might be an additional saving potential, e.g. by using lower water temperatures and volumes for these processes.

Best Available Technology of Coffee Machines (BAT)

Highly efficient coffee machines feature the above discussed efficiency technologies in an optimal combination. Presently, comparable measurement results of a broad selection of coffee machines are not available because measurement methods are not yet harmonised (see below). The analysis of many results (FEA/CECED-forms) and own (Topten) measurements suggest that several coffee machines – portioned as well as fully automatics – are very nearby the theoretical "Best Available Technology".

Experience shows also that good efficiency can be achieved not only with flow-type heaters, but also with relatively small, well-insulated boilers/thermo-blocks and energy saving temperature control. Presently it seems that there are no really new "Best Not Available Technologies" (BNAT) to be expected for the types of coffee machines in the focus. The physical analysis of the functions and energy flows prompts this assumption.

A crucial issue considering energy efficiency is the possible affection of coffee quality by too restrictive efficiency measures. An example: optimal coffee with espresso quality requires all objects coming in contact with the brewing unit and brewed coffee to be hot. The challenge is to come near to that without the need of keeping all objects at high temperature. A possible solution is to discard a very small amount of coffee first leaving the brewing unit. The effect is similar to rinsing the machine before brewing.

Another development area for coffee machine efficiency is the consumption of energy and water for maintenance and hygiene purposes.

Flow-type heater technology might lead to higher electric power demand: actually, most coffee machines have a maximum power input of 1'000 to 1'500 W. To enable a machine to brew two cups at once in a short time, power ratings of 2'000 W or more may be attractive. Problems may arise for household electrical installations.

Preparatory Study on Non-tertiary Coffee Machines Lot 25

Since mid of 2009, the preparatory study on non-tertiary coffee machines Lot 25 [6] is being carried out by BIO Intelligence Service (Paris) for the European Commission DG ENER in the context of the Eco-design Directive. The preparatory study follows the Methodology for Eco-design of Energy-using Products (MEEuP), which is mandatory for all Eco-design preparatory studies, comprising 8 tasks.

Methods to Measure the Energy Consumption of Coffee Machines

Presently Used Measuring Methods

The existing standard IEC 60661 [8] does not include a method for measuring the energy consumption of coffee machines. Therefore two initiatives have developed each a measuring method. Both methods are applied in Europe in parallel at present.

One method was developed by Euro-Topten and S.A.F.E. (year of implementation: 2007, last update May 2009 [9]) and was presented at EEDAL 2009 [10]. It is applied by Topten for “Best Products of Europe” (presented on www.topten.eu) and for national Topten-sites (e.g. www.topten.ch), by The Blue Angel (for RAL-UZ 136 [11]), by manufacturers to have their high efficient coffee machines presented on Topten websites and by Swiss electrical utilities and Swiss communities for rebate programmes based on Topten lists.

The other method was developed in 2008/2009 by the Swiss Association of the Domestic Electrical Appliances Industry FEA with the contribution of CECED. It is applied by manufacturers to get the voluntary Swiss energy label (class A to G, introduced in autumn 2009). The measuring method was adopted by CECED.

As shown in Table 4, both methods have benefits and drawbacks.

Table 4. Benefits and drawbacks of the Euro-Topten/S.A.F.E.- and the FEA/CECED-measuring methods for coffee machines.

	Euro-Topten/S.A.F.E.-Method	**FEA/CECED-Method**
Implementation	**2007**	**2009**
Benefits	• Measurement along a “coffee period” • Simple proceeding irrespective of ”energy saving modes”	• Measurement of coffee preparation and steaming function
Drawbacks	• Presumed coffee preparation energy consumption: standard value of 20 kWh/year (Note: corresponds well to measurements, see Figure 3: 9 Wh for 80 g, 2'190 cups per year)	• Impact of auto-power-down delay and “energy saving modes” not adequately considered

Future Test Standard: Revised IEC 60661

As the existing standard IEC 60661 [8] does not include a method for measuring the energy consumption of coffee machines and because both presently used measuring methods have their benefits and drawbacks as described above, one revised European approach improving the existing methods validated by CENELEC is in development in a collaboration of CECED, manufacturers, Topten and S.A.F.E. (working group TC59X_WG15).

The revised IEC 60661 will contain two measuring procedures: one for coffee machines with pressure (high and low pressure) and one for drip-filter machines (no pressure).

Proposal for Pressurized Coffee Machines

The measurement follows along a reasonable usage cycle, the so called "coffee period": start of the coffee machine from cold, heating up, wait until ready, wait one minute, coffee preparation at defined points in time (1 minute after ready (1 x 40 g, 1 x 120 g) and at minute 30 (double coffees: 2 x 40 g), in total 240 g), measurement of the energy consumption at minute 40 and at minute 100 (end of the "coffee period"). During the measurement the behaviour of the machine will be as set by factory (e.g. auto-power-down, delay-time, "energy saving mode", rinsing etc.).

Coffee temperature – as one of the indicators for good coffee – is measured. In case the temperature does not reach 76°C, a correction of the consumed energy is made.

In case the actual coffee mass deviates from the nominal, a correction is made.

In case the machine can only make single coffees the double coffees are replaced by 2 singles of the same weight to be made immediately in sequence.

If a machine does not have a power management system including automatic switching to standby or off mode, the value of the energy consumption from minute 40 to minute 100 shall be used as hourly standby mode energy consumption.

If the machine has a power management system that switches the machine to off mode, the off mode power consumption will be taken as standby power.

Steam production is measured separately.

The consumption of energy and water for maintenance and hygiene purposes is not considered in measuring method.

Proposal for Drip-Filter Coffee Machines

A draft proposal was worked out by Topten and S.A.F.E.. It will be discussed at the next CENELEC-meeting held in mid of May 2011. This will be after the closing time for this paper and thus no further details can be provided in this section.

Energy Saving Potential of Coffee Machines

The electricity consumption of coffee machines and its saving potentials are of high relevance. However, the annual energy consumption of coffee machines depends on the applied measuring method and the assumptions made on the consumer behaviour. It is intended that the daily energy consumption of coffee machines will be calculated as followed:

- Pressurized coffee machines: 3 coffee periods per day (measured according to the upcoming revised IEC 60661 (drafted), 720 ml, 5 h), 8 hours in standby, 11 hours in off.
- Drip-filter machines: 2 coffee periods per day, energy consumption normalised to 900 ml.

First measurements according to the upcoming revised IEC 60661 (drafted) were undertaken by some manufacturers. However, there cannot be given estimations on the energy saving potential on that basis, because no broader data are available and the tasks of lot 25 are not yet finished at the present time.

According to estimations by Topten more than 10'000 million kWh or up to 2'000 million Euro electricity costs could be saved per year, if 100 million coffee machines in Europe were replaced by energy efficient models (old coffee machine: 170 kWh/a, new coffee machine: 50 kWh/a).

Market Transformation of Coffee Machines

Since 2005, the energy efficiency of coffee machines has been improved as follows (based on the expert knowledge of Topten and S.A.F.E., see also [4]):

Until 2005 most coffee machines had to be switched off manually after use. If consumers didn’t do so, the coffee machines stayed in the ready mode, which resulted in a high energy consumption (heating unit at 85°C to 90°C).

When launching the www.topten.ch presentation of the most efficient coffee machines available on the Swiss market in 2007, the auto-power-down function was found only in the first few machines. However, the factory settings of the auto-power-down delay time were at 3 hours and more. Nowadays all (non-tertiary) coffee machines of the important manufacturers entering the market are equipped with an auto-power-down function. Factory settings of the auto-power-down delay have been shortened: for some models the factory setting is 2 hours (or more), for many models between 10 minutes and 1 hour and for some models 1 minute or even below.

The first coffee machines with an auto-power-down had a standby consumption of about 3 W. Since January 2010 the standby of coffee machines is regulated by the Eco-design Regulation for standby and off mode consumption [7] and max. 1.0 W (without display) and max. 2.0 W (with display, tier 1) are required. Nowadays, coffee machines typically have a standby of 0.5 to 0.9 W. However, more and more models switch even to zero power.

Coffee machines that are equipped with an “energy saving mode” that lowers the temperature of the heating element after a certain time entered the market in 2009.

In the past few years, thermal losses of heaters were also lowered by better insulation of the hot parts of coffee machines such as thermo-block and water heaters of any kind. Before 2005 certain models needed 30 W and more in ready mode (even without actively heated hot plate), today efficient models hardly exceed 10 W.

First (portioned) machines equipped with flow-type heaters entered the market in 2008.

Initiatives to Push Market Introduction of High Efficient Coffee Machines

The following initiatives have been undertaken in the last few years to push the market introduction of high efficient coffee machines:

Measurements of the Energy Consumption and Tests

Since 2003 many measurements and tests on coffee machines have been undertaken by Topten and S.A.F.E. according to their measurement method [9]. The results and the expert knowledge flew back to the manufactures. Many of them incorporated the input and enhanced the energy efficiency of their machines during the past few years.

Criteria for High Efficient Coffee Machines by Topten and by The Blue Angel

In 2007, Topten developed selection criteria for high efficient coffee machines (fully automatic machines and portioned machines) and started to present the most efficient coffee machines in Switzerland on www.topten.ch (measured according to [9]).

The presentation of the most efficient coffee machines available on the European market followed in 2008 (www.topten.eu – Best Products of Europe). The criteria strengthened in parallel to the technical development of coffee machines.

The Blue Angel developed criteria for high efficient coffee machines in summer 2009 (RAL-UZ 136 [11]). The measuring method and energetic criteria are harmonized with Topten.

Topten and The Blue Angel will adopt the revised IEC 60661 standard as soon as possible.

Rebate Programmes

In Switzerland, the cradle of Topten, first rebate programmes for high efficient coffee machines were launched in 2007 by the Zurich Municipal Electric Utility (ewz). Selection criterion is Topten (being listed on www.topten.ch). Other Swiss electric utilities and Swiss communities soon followed the example of ewz.

Energy Label

In 2006, Topten and S.A.F.E. proposed the introduction of an energy label for coffee machines in a contribution at EEDAL 2006 [12]. In autumn 2009, a voluntary Swiss energy label was introduced in Switzerland ranging from class A to G, based on the FEA/CECED-measuring method.

Policy Recommendations

Policy measures are needed to realise the high electricity saving potential of coffee machines. The Eco-design Regulation for standby and off mode consumption is also relevant for coffee machines, but the delay-time for the auto-power-down is not yet defined. Furthermore, Minimum Energy Performance Standards MEPS and an EU energy label for coffee machines should be established. Also the production of capsules and pads should be taken into account and an ambitious timetable for the implementation should be set up.

Appropriate Implementation of the Standby and Off-Mode Regulation

Since January 2010 the “horizontal” (covering all products) Eco-design Regulation for standby and off mode consumption [8] is in force and requires also coffee machines to have a standby consumption of no more than 1.0 W (2 W with display). From 2013 the limits will be 0.5 W (1 W with display). As for non-tertiary coffee machines there is no need to display any information in standby mode, Topten recommends that only the lower values should apply (tier 1: 1.0 W; tier 2: 0.5 W). Nevertheless, zero standby represents BAT and helps manufacturers to get a better energy class.

Introduction of Minimum Energy Performance Standards MEPS

Effective Eco-design measures should include MEPS targeting the coffee machines’ energy consumption during the coffee period. Maximum limits should be guided by the most efficient products on the market. As the measuring method according to the revised IEC 60661 is not yet definite maximum thresholds cannot yet be proposed at the present time.

From January 2013 energy-using products must have a power management function switching to a standby or off mode “after the shortest possible period of time appropriate for the intended use of the equipment” (tier 2 of [7]). For non-tertiary coffee machines, auto-power-down will therefore be a need. For coffee machines the maximal delay from the last activity is not yet defined. Topten recommends a maximal delay time (factory setting) of 15 minutes for portioned machines (high and low pressure), 30 minutes for fully automatic machines and machines with piston lever and 60 minutes for drip-filter machines without thermos jug.

Introduction of an EU Energy Label for Coffee Machines

An energy label would be a very effective measure to help buyers to recognise the most efficient products on the market. As retailers like to offer products of best label classes the label would give incentives to industry and trade to develop and offer energy-efficient coffee machines. It further would be a useful tool for promotion programmes.

Topten recommends the introduction of an EU energy label for all types of coffee machines such as fully automatic machines, portioned machines (high and low pressure), machines with piston lever as well as drip-filter machines and combi machines. The measurements of the energy consumption shall follow the revised IEC 60661 (in work).

For the different types of coffee machines are different labelling schemes recommended (e.g. fully automatic machines have a more sophisticated brewing unit because coffee powder has to be processed, instead of capsules or pads).

The Production of Capsules and Pads Should Also Be Taken Into Account

With respect to the overall energy and resources consumption of coffee preparation the production of capsules and pads should also be taken into account. The capsule production is likely to (over-) compensate the somewhat lower energy consumption of portioned machines for a coffee period. As the energy and resources expenses of capsules cannot be influenced by the buyers, a declaration of the eco-balance of capsules and pads should be discussed.

Ambitious Timetable for Implementation

Manufacturers strongly improved their coffee machines over the past three years. No further big energy saving potential is expected (brewing of coffee: no substantial energy gain is possible, and flow-type heaters are introduced in the market). Manufacturers shall get incentives very soon!

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission’s Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in two more European countries (www.topten.eu).
- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.
- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation - www.repic.ch) and SECO (State Secretariat for Economic Affairs – www.seco.admin.ch) who supports the build-up of Topten China.

References

[1] www.topten.eu – Best Products of Europe

[2] www.topten.info – International Platform for Best Products

[3] GfK Group, Nuremberg, Germany, www.gfk.com

[4] Nipkow J., Josephy B., Bush E., Pilone A. *For a tasty but efficient coffee*. Paper for the 2011 Summer Study of the European Council for an Energy Efficient Economy. 6-11 June 2011.

[5] Nipkow J., Bush E. Stand-by consumption of household appliances. Swiss Agency for Efficient Energy Use S.A.F.E. on behalf of the Swiss Federal Office of Energy SFOE, Berne 2003, Download: www.electricity-research.ch (search: appliances)

[6] Ecodesign of EuP. Non-tertiary coffee machines lot 25. BIO Intelligence Service, Paris. www.ecocoffeemachine.org

[7] European Commission. Commission Regulation (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment.

[8] IEC 60661 Ed. 2.2, 2006 – 02. Methods for measuring the performance of electric household coffee makers.

[9] *Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for Household Use.* Euro-Topten and S.A.F.E., 9th May 2009. Download: www.topten.eu

[10] Bush E., Nipkow J., Josephy B.; Heutling S., Griesshammer R. *Strategies to Enhance Energy Efficiency of Coffee Machines.* Topten International Group TIG, Swiss Agency for Efficient Energy Use S.A.F.E., German Federal Environment Agency, Oeko-Institute, EEDAL-Conference, Berlin 2009, Download: www.topten.eu

[11] RAL-UZ 136. Espressomaschinen / Kaffeemaschinen mit hohem Druck. Vergabegrundlage für Umweltzeichen. Der Blaue Engel, Juni 2009. Download: www.blauer-engel.de

[12] Nipkow J., Bush E. *Energy label for coffee machines.* Swiss Agency for Efficient Energy Use S.A.F.E., EEDAL-Conference, London 2006.

Dishwasher household loads and their impact on the energy consumption

Dr. oec. troph. Christian Paul Richter

Household and Appliance Technology Section, Institute of Agricultural Engineering, University of Bonn

Abstract

The evaluation of the energy consumption of dishwashers depict on the Energy Label is based on the test standard EN 50242, using so called place settings. But real-life dishwasher loads are hardly comparable to the dishes used in the dishwasher performance test as not only pots and pans are found in peoples' dishwasher but also items made of plastic and wood, materials which are not included in the test standard. Due to the amount of dishes and the mixture of materials with different heat intake capacities this instance inevitably has an influence on the energy consumption of the dishwasher and its efficiency.

The combination of experimental and empirical research in this paper shall clarify how consumer dishwasher loads look like in everyday life and how the energy consumption depends on the load size. Therefore, real life dishwashing behaviour was observed in an in-house consumer survey in 160 households with dishwasher in four European countries (Germany, Italy, Sweden and the UK). Pictures of the household dishwasher loads were analysed towards their capacity use, number, type and material of dishes and the energy consumption was calculated based on the load weight. The basis for these calculations is the testing of three different dishwasher models towards the dependency of the dishwasher energy use on the size of the load.

Background

The frequency of running the dishwasher depends on various factors such as household and dishwasher size, the number of spare dishes (loading efficiency) as well as on household and personal characteristics (e.g. lifestyle, frequency of eating out or the number of dishes used per meal). These factors have also implications on how fully the dishwasher is loaded and therewith also how much energy is used in the process.

According to the European performance test standard EN 50242 the dishwasher load consists of 140 items, including so called place settings. 12 place settings represent the amount of dishes used by four persons during one day. This load and the energy saving programme (or reference programme) result in the energy consumption depict on the Energy label [1].

However, apart from the question what kind of programme is really chosen in the daily use of dishwashers in European households, the amount and composition of dishes used in the test standard are lacking of consumer reality. Unfortunately, on real-life loading behaviour of households in Europe is just very little information available.
In 2004 Zott & Hubbuch investigated the dishwasher loads of 20 German families in regard to the number, size, material and style of dishes. The analyses of pictures of the families' dishwasher loads indicated that people somehow follow their own loading scheme as only little changes in the loading pattern within one household were observed and that insufficient usage of the dishwasher capacity is mainly down to restrictions caused by the shape of dishes. Furthermore, the research points out that real-life dishwasher loads are hardly comparable to those used in dishwasher performance tests as not only pots and pans are found in families' dishwashers but also items made of plastic, a material which is not included in the test standard. The study reveals that on average 20% of all items loaded were made of plastics [2].

Due to different heat intake capacities of materials this instance inevitably has an influence on the energy consumption of the dishwasher. The Group for Efficient Appliances (GEA) carried out an analysis to demonstrate where energy savings could be made through adjusting the design and use of dishwashers and found that there are effects of consumer behaviour on the energy use, particularly noticeable for the loading efficiency. The GEA made distinctions between the real-life case and base case. The base case is based on the International Standard for dishwasher performance test (IEC436). It prescribed a load of 22kg of ceramics and 3kg of steel (12 place settings), whereas GEA estimates that consumer use an average load of 4.5kg steel (considers also pots and pans) and 11.5kg ceramics (mass equivalent of 7 place settings) in real-life (Table 1).

Table 1: Comparison of dishwasher's water and energy consumption for the GEA base case and GEA real-life case

	Mass (in kg)	**Equivalent place settings**	**Programme**	**Energy use per cycle (in kWh)**	**Water per cycle (in l)**	**Energy per PS (in kWh)**
GEA base case	25	12	Normal 65°C	1.651	24	0.1376
GEA real-life case	16	7	Normal 65°C	1.517	24	0.2167

Source: GEA 1995, p. 3.22 et seqq.

In total the water consumption stays the same but as the lower amount of dishes intakes less thermal energy the total energy consumption is some 8% less (Table 1). But it also shows that the energy use does not decrease to the same degree as the weight of dishes does (-36%) and so the energy consumption per place settings increases by 57% [3]. Overall, a less efficient loading behaviour decreases the total energy consumption of dishwashers but is still way less efficient if the dishwasher would be loaded to its full capacity.

As every dishwasher is configured differently, it is advised to follow the manufacturers' recommended loading guidelines. These guidelines usually also contain the advice to load the dishwasher to its full capacity before starting the wash. From the consumer perspective the dishwasher's capacity is normally used completely: For the European Commission a preparatory study for Eco-design requirements of energy using products (EuPs) was conducted in 2006, interviewing 2500 European citizens from 10 different countries about their dishwashing habits. The findings show that nearly 90% of the respondents believe that their machines are fully filled, respectively almost overloaded before the wash cycle gets started. Only about 10% admit to run the dishwasher also when not completely filled or do not care about the amount of loaded items in the appliance [4].

As a comparison between people's attitude and the actual loading efficiency could not be found in the literature and the knowledge of real-life dishwasher loads is limited in general, the present work focuses on these matters and also looks into the question, how the load size influences the energy consumption of a dishwasher. Therefore, data of an international consumer study, in which the dishwashing habits of 160 households with dishwasher in four European countries were observed, was combined with results of the experimental testing of dishwashers towards the dependency of the energy consumption on the load size. In the following the findings of both studies will be presented, including an analysis on the efficiency of loading the dishwasher, the composition of materials and the energy use of dishwashers based on the load weight.

Methodology

Observation of dishwashing habits in the domestic environment

In order to gather varieties of dishwashing habits in Europe and their impact on the water and energy consumption in the kitchen, in total 200 households, 50 households in each of four European countries (Germany, Italy, Sweden and United Kingdom) have been researched. 160 of the observed households possessed a dishwashing machine.

For the recruitment of participants, external market research firms (ODC Services GmbH and Toluna Inc.) randomly selected householders and invited them to take part in the study. A screening questionnaire was designed in order to gather socio-demographic characteristics and to make sure that participating persons regularly perform the washing up task and are involved in the decision making process of the purchase of large household appliances.

The selection of households was limited to the household size and the availability of household appliances (10 out of 50 households per country did not possess a dishwashing machine). Pre-settings for the recruitment were made according to these two indicators in order to assure comparability between the countries. Then, these households were visited and interviewed.

The survey was conducted in four steps in major cities and their suburban areas of the selected European countries (Table 2).

Table 2: Research schedule

Country	Area	Period of time
Germany	Cologne/ Bonn	May – July 2007
Italy	Milan	September – November 2007
Sweden	Stockholm	March – May 2008
United Kingdom	London	July – October 2008

After interviewing the householders the home observation started. During a period two weeks all participants were asked to wash dishes as they would normally do and to fill in a dishwashing diary for every dishwashing procedure either by hand or in the dishwasher. The diaries had been designed to include information on the date and duration of a cycle, the number and types of dishes cleaned, dishwashing practise, programme choice and other specific information.

In addition to the form for each dishwasher load, participants were asked to take at least two pictures of the loaded dishwasher before they started the programme; one picture of the upper rack and one of the lower rack. The purpose of these pictures was to evaluate loading patterns in everyday-life dishwasher loads and to analyse the use of the dishwasher's capacity.
In total, 1071 dishwasher cycles have been analysed. For around 80% of the cycles, pictures of the whole load have been available for the evaluation. Regarding the degree of space used in the upper basket (UB) and lower basket (LB) four categories have been differentiated: "extremely filled" (> 100% of space used, items on top of others), "fully filled" (90-100% of space used), "moderately filled" (60-90%) and "slightly filled" (<60%). The possibility to rearrange items in order to achieve a higher degree of capacity use was also taken into account.

Calculations for the energy consumption of dishwasher cycles

In order to include findings on the energy consumption for automatic dishwashing processes, which reflect that the energy consumption consistently increases with an increasing load size (cf. GEA, 1995), certain assumptions had to be made:

1. The energy use is based on average consumption values according to the age and size of the household dishwasher (Table 3).

Table 3: Assumed energy consumption per cycle according to the size and age of the appliance (in kWh)

Age of dishwasher (in years)	Standard size (60 cm)	Small size (45 cm)
< 1	1	0.8
1 – 2	1.05	0.83
3 – 5	1.11	0.88
6 – 7	1.25	0.96
8 – 10	1.5	1.2
> 10	1.7	1.4

Note: For household possessing a Countertop dishwasher 0.65 kWh per cycle were assumed

Source: Preparatory Studies for Eco-design Requirements for EuPs Lot 14 [5]

2. The weight of the load was calculated based on the actual load and assumptions regarding the weight of the different types of dishware as shown in table 4.

Table 4: Assumptions for calculations on weight of dishwasher load

Category	Item	Assumed weight (in g)
Plates	Dinner plates	547
	Soup plates	458
	Dessert plates	249
	Saucers	141
Drinking vessel	Glasses	109
	Cups	119
Bowls	Small	143
	Medium	390
	Large	657
Cutlery	Silverware	38.4
	Serving cutlery	58
Pots	Small	573
	Medium	1302
	Large	1903
	Lids	326
Frying pans	Small	1039
	Large	394
	Casserole dish	1322
	Plastic items	318
	Wooden items	231
	Other items	528

Note: Weights of plates, drinking vessels, bowls and cutlery are based on weight values of place settings according to EN50242; remaining categories are based on arithmetic means of at least 4 different items weighted

Source: Own measurements, EN 50242 [1]

3. The values for the energy use were then processed according to the weight of the dishwasher load. Based on the experimental research, which particularly investigated the influence of the load size on the energy consumption for a dishwasher, an equation has been formed to calculate the energy consumption with respect to the weight of the dishwasher load:

$$E = Ea - [g * (DS - PSe)]$$

where:

E*a* ... Assumed consumption value according to Table 3
g ... Gradient (g = 0.0128; as average of equation gradients depict in Figure 1)
DS ... Dishwasher nominal size expressed in number of place settings (Standard size = 12, Small size = 9)
PS*e* ... Number of equivalent place settings = calculated weight of dishwasher load/ weight of one place setting according to EN 50242 (= 23.876 kg/ 12)

In case of the absence of pictures of the dishwasher load the cycle got accounted with no adjustment to the load weight.

Experimental research on dishwasher energy use dependency on load size

In order to find a basis for the calculation described above an experimental study was conducted. The aim was to measure the effect of load size on the energy consumption of three different dishwasher models representing the majority of the European dishwasher market.

In the test procedure each dishwasher model was tested according to the EN 50242:2008, except that the cleaning and drying performance was not assessed; the number of replicate test runs was reduced from five to three for each condition tested; the sets of tests were carried out using no detergent; and that neither standard soils nor ballast soil were used.

For each test set the number of place settings loaded into the dishwasher was reduced by 3 place settings, starting with 12 place settings (PS). The appliances (Miele G1222, Bosch Zeolith SD6P1B, Electrolux ESF6150) were operated on the programme which is the one identified by the manufacturer for energy label testing.

Results

Sample

As shown in Table 5 the survey was conducted in equal parts for the four countries (each 25%). With 63% the share of women was substantially higher than that of men, and the distribution of household sizes corresponds to the pre-settings made with smaller deviation (on maximum ± 5%) due to the sample size.

In terms of the householders' age it can be seen that the biggest shares are the age groups 35 to 44 years (33 %) and 45 to 54 years (31 %), especially identified as family households. Around a quarter of all participants lived in single-person households and 12 % were extended households with at least five members. Participating households were possessing different sizes of dishwasher, from counter top dishwashers (5 PS) over small size (9 PS) to standard size dishwashers (12 PS). The most common dishwasher size amongst the researched households was the standard size (81 %), followed by the small size (14 %). Only 9 households possessed a countertop dishwasher, whereas the number of those households was particularly high in Sweden (n=6).

Everyday-life loads and use of dishwasher capacity

As described before, the majority of the households were using a standard size dishwasher; therefore the findings in this part of the work are based on this type of dishwasher only. Figure 1 presents the average number of dishes loaded into the dishwasher.

Table 5: Demographic characteristics of participating households

Demographic characteristics	No. (%) of respondents
Country (n=160)	
Germany	40 (25,0)
United Kingdom	40 (25,0)
Sweden	40 (25,0)
Italy	40 (25,0)
Gender of householder (n = 160)	
Female	100 (62,5)
Male	60 (37,5)
Age group of householder (n = 160)	
24 years and younger	3 (1,9)
25 – 34 years	28 (17,5)
35 – 44 years	52 (32,5)
45 – 54 years	49 (30,6)
55 – 64 years	22 (13,8)
65 years or older	6 (3,8)
Household size (n = 160)	
1 person	38 (23,8)
2 persons	39 (24,4)
3 persons	36 (22,5)
4 persons	35 (21,9)
5 and more persons	12 (7,5)
Dishwasher size (n=160)	
Standard size (60 cm)	129 (80,6)
Small size (45 cm)	22 (13,8)
Countertop dishwasher	9 (5,6)

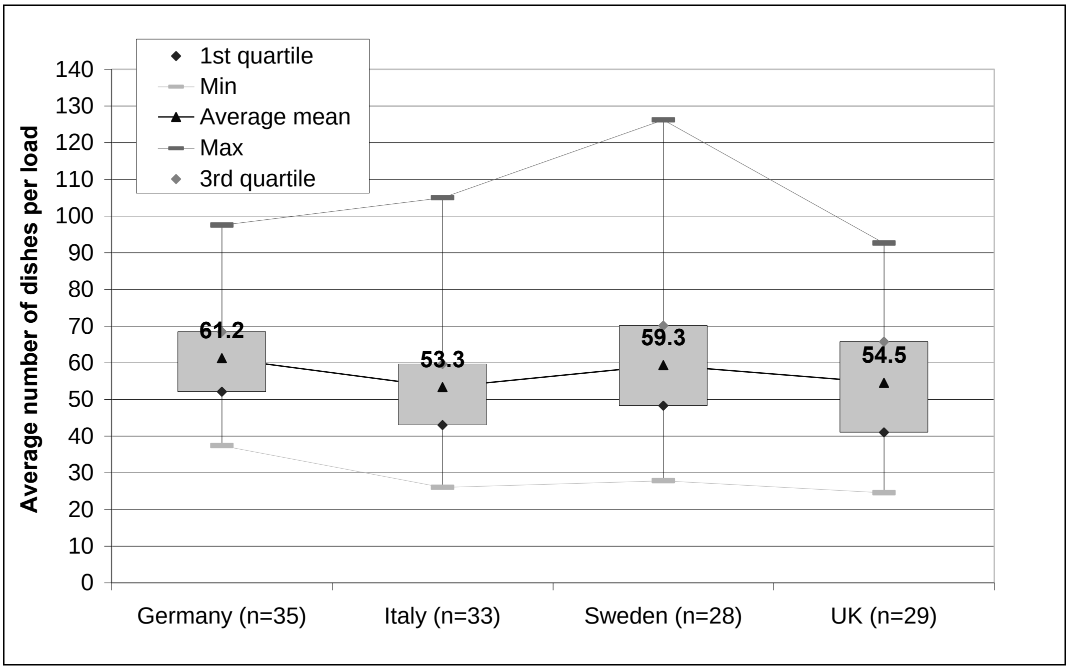


Figure 1: Average number of items per dishwasher load

Basis: Household average, standard size dishwashers only, loads with and without loading pictures

It shows that the highest average amount of dishes per dishwasher load is found in Germany (61 items), followed by Sweden (59 items) and the UK (55 items); the lowest number of loaded dishes was observed in the researched Italian households (53 items). The majority of households load the dishwasher with a number of dishes ranging from 40 to 70. The highest household average was found in Sweden (127 items), the lowest in the UK (24 items).

However, when asked about the extent of dishwasher capacity use, the majority of the people stated that they load the dishwasher in such a way that it is fully filled or even nearly overloaded, altogether 90% of the participants claimed to do so in the interview. Less than 10%, especially single- and 2-person households with standard size dishwashers, said they do not fill the machine to its full capacity but run it even with a relatively few number of dishes inside.

After the period of home observation all dishwasher loads were assessed towards the degree of space used in the upper (UB) and lower basket (LB). It shows that in less than 40% of all dishwasher loads the machines are really filled to the full capacity (Figure 2), whereas the proportion of extremely filled baskets is more common with the upper rack (4%) than with the bottom rack (2%).

The proportion of baskets whose space is only slightly used is relatively high with on average 20%, but the highest in UK households (44%). Here consumers filled only 6% of the lower baskets and 12% of the upper baskets to its full extent. The relatively best dishwasher capacity use can be observed in Sweden, where the proportion of slightly filled baskets is the least.

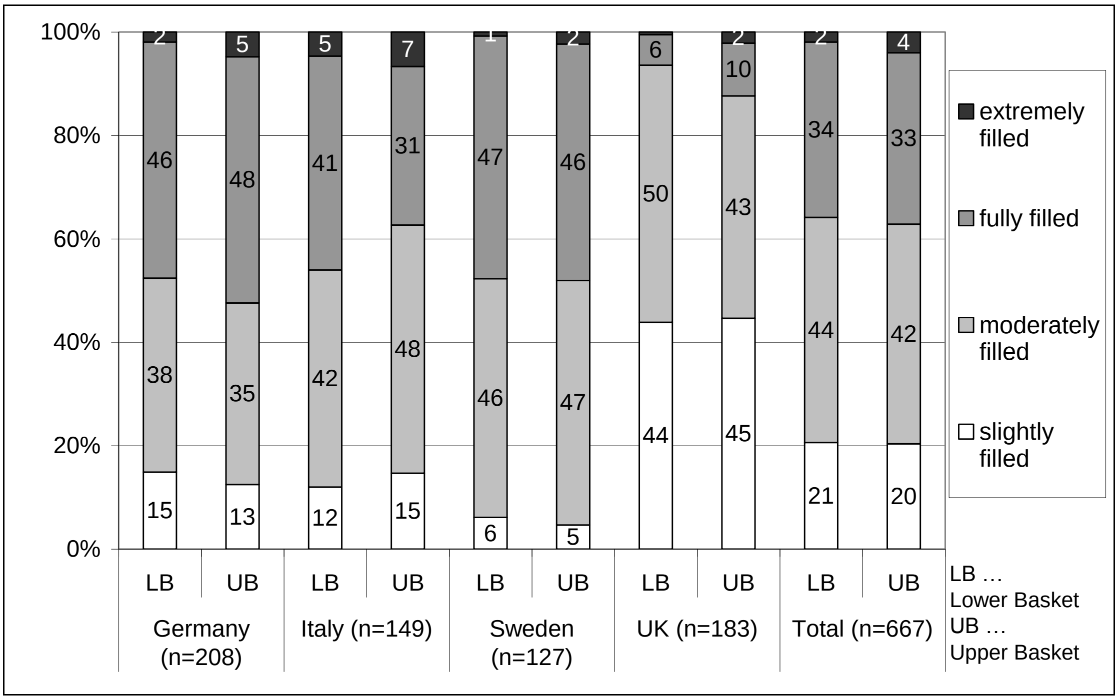


Figure 2: Dishwasher capacity use based on used space (in %)

Basis: Dishwasher loads with pictures available, standards size dishwashers only

As described all dishes loaded into the dishwasher were assigned to a specific weight according to type and size of the item and the weight of the load was then calculated. In Figure 3 the households average load weight is depict. It can be seen that none of the households' load weights ever reach the level of 12 place settings used in the test standard EN 50242. The arithmetic means of all the countries hovering around a level which is half the weight of the standard load, whereas the researched households in the UK have the lowest average values (10,3 kg) and the Swedish and Italians the highest (12 kg). The differences between Germany, Italy and Sweden are statistically not significant ($p > 0.05$), but the average dishwasher load weight of the researched UK households differs highly significant ($p < 0.01$) from the rest of the countries' means.

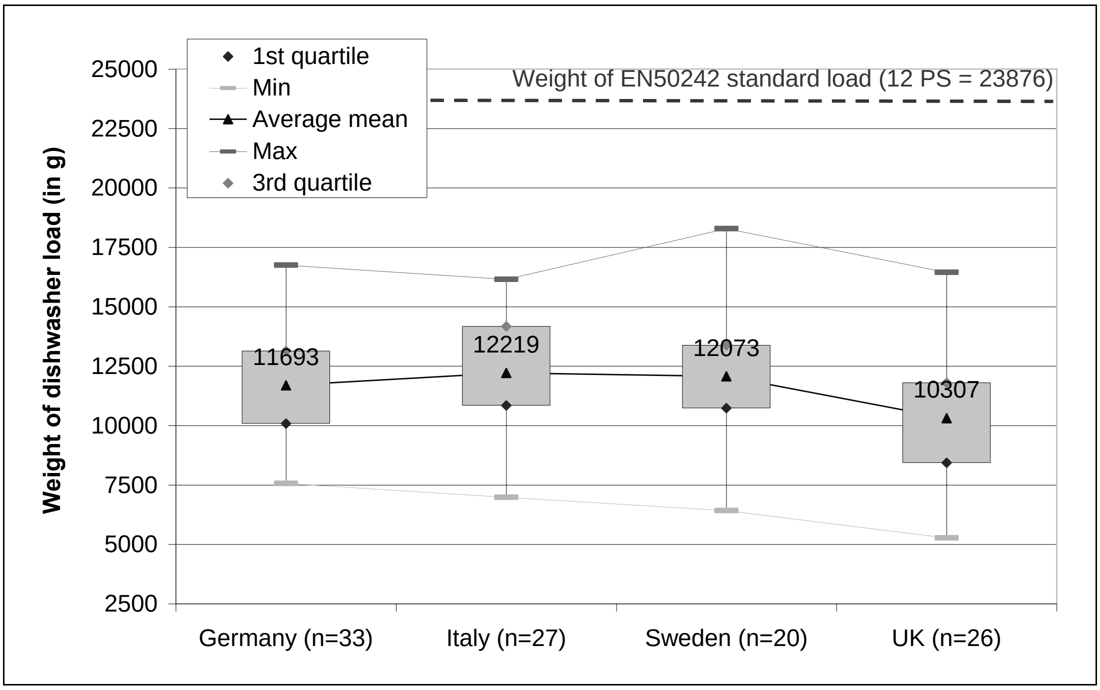


Figure 3: Weight of dishwasher loads

Basis: Average of households, loads with pictures and standard size dishwasher only

The relatively low average weights of the researched household loads are not only caused by the number of dishes loaded but also influenced by the kind of materials the items are made of. As depict in Table 6, the observed number of porcelain items in household loads is significantly lower than in the EN 50242 standard load (26-31 % vs. 46%), and way higher for the category of glass items (12-17 % vs. 9%). The shares of metal items in the countries' loads, including for example pots, pans and cutlery items are similar to the one of the standard load (46-52 % vs. 46 %). However, the EN 50242 standard load does not consists of pots and pans, and also plastic and wooden dishware is not included. The observed household loads on the other hand do have a considerable amount of dishes included that are made of wood or plastics (together between 5 and 11 %).

Table 6: Average distribution of materials in household loads and EN 50242 standard load

	Germany (n=33)	Italy (n=27)	Sweden (n=20)	UK (n=26)	EN 50242
total number of items	63,1	57,3	62,3	54,8	140
% of porcelain items	28,7	26,2	29,7	31,1	45,7
% of glass items	14,2	12,4	17,4	13,7	8,6
% of metal items	46,1	52,2	45,4	50,1	45,7
% of plastic items	10,2	7,6	6,3	4,6	0,0
% of wooden items	0,8	1,6	1,1	0,5	0,0

Basis: Average of households, loads with pictures and standard size dishwasher only

Source: Own measurements, EN 50242

Dishwasher energy consumption and its dependency on the load size

Most of the energy used during a dishwasher cycle is required to heat up the water and to run the motor pump. However, through the course of the cleaning programme the loaded dishware is also heated up by heat energy transferred from the hot water. The amount of energy used in this particular process is determined by different heat intake capacities of the dishware materials but first and foremost by the load size (amount of dishes loaded into the dishwasher).

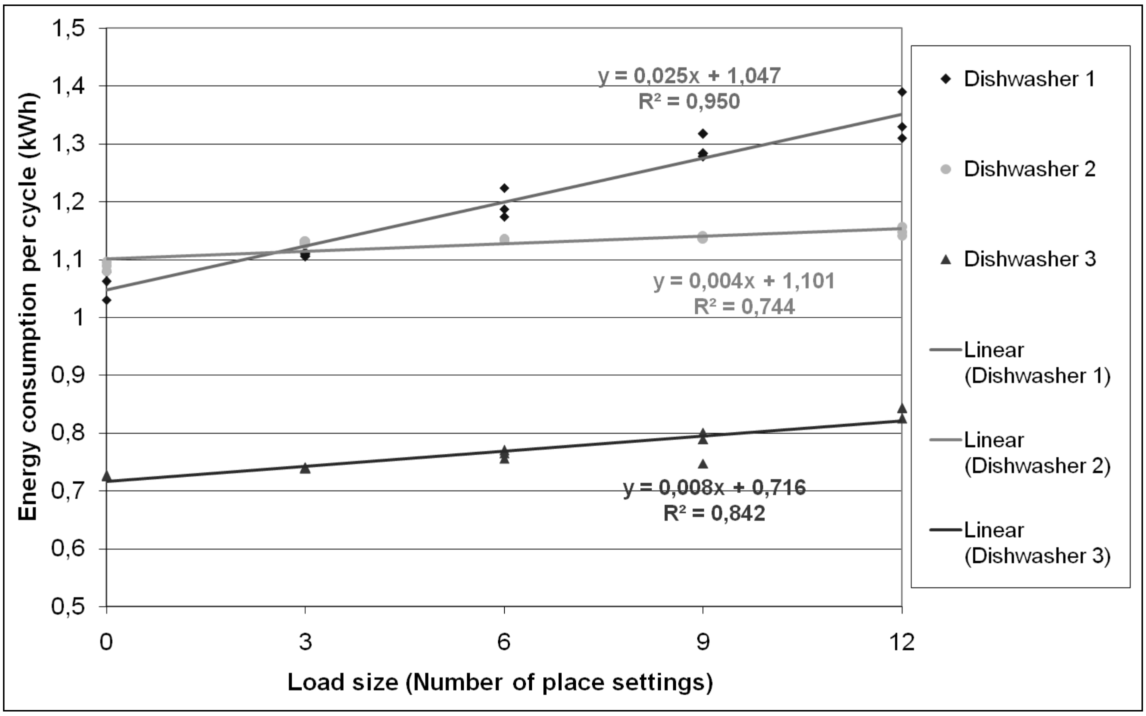


Figure 4: Influence of load size on the energy consumption of three different dishwashers

The experimental research on three different dishwashers has proven that the energy consumption is decreasing when the load size is lowered (Figure 4). The extent of decline in energy use however differs between the tested machines. Dishwasher 1, the oldest machine in the test (approximately 12 years), shows the strongest correlation between load size and energy use. The linear equation for this dishwasher indicates that around 0.3 kWh per cycle is used to heat up the dishes when the dishwasher is fully loaded. So 22% of the total energy use per cycle is due to heat intake of the dishware.
This effect is not as big with the younger dishwasher models. For dishwasher 3, the model with the lowest total energy consumption in the test, the heat energy intake of dishes is at around 12%. Only with dishwasher 2 the correlation between load size and energy use is very weak. The difference between the empty test runs (0 PS) and fully loaded ones (12 PS) is with 0.05 kWh just marginal. This is probably due to the type of controlling and timing of the cleaning programme for this machine.

In general the experiment shows that although the total energy consumption decreases by smaller load size, the degree of reduction in the energy use does not equal the degree of load size reduction. Consequently, the energy use per place setting increases and so the efficiency of the dishwashers is lowered.

In order to calculate the energy consumption of dishwashers in the surveyed households in dependency of the actual load weight the average of all three linear gradients was taken (g=0.0128). The factor is moderate and also seen as good average for dishwashers in the European market.

The results of the calculations are presented in Figure 5. It depicts the energy use of households per cleaned item as per item based values are found to be more practicable in order to compare households of different household sizes and those with dishwashers of different sizes.
It shows that the surveyed households in Sweden used on average the smallest amount of energy per item (19.7 Wh) to clean the dishes in the dishwasher, the Italian households with 22.4 Wh per item the highest amount. However, the differences emerging in the cross-country comparison are not statistically significant. This is due to the fact that the variances within the countries are generally very high. For example, the Swedish household with lowest value used only a little less than 10 Wh per item; the one with highest consumption value in this country used four times more. The variance in the group of observed British household is even bigger. However, 50% of the households range between 15 Wh and 25 Wh per item.

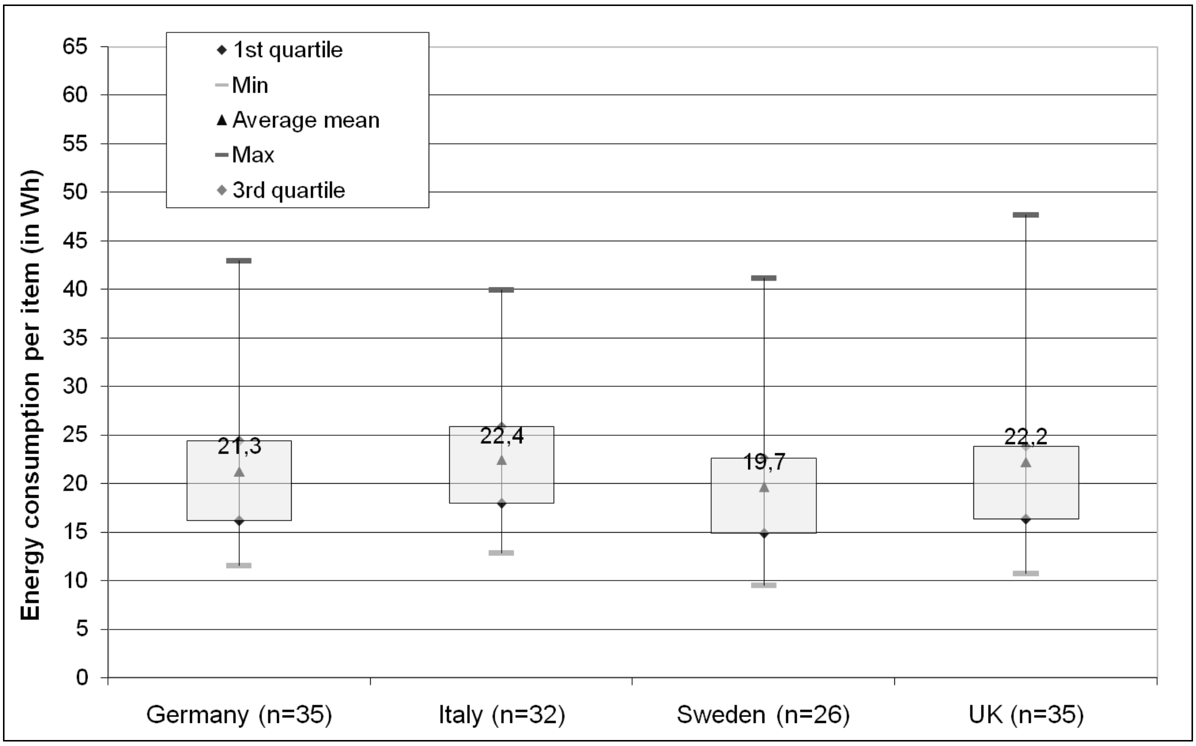


Figure 5: Dishwasher energy use per item

Basis: Household average, only households with at least 75% of the cycles with loading pictures, standard and small size dishwashers only

Summary and Conclusion

In the present work the loading habits of consumers and the implications of the load size on the energy consumption of dishwashers have been investigated.
In terms of the loading efficiency of dishwashers in real life the research found that there is partly a big gap between consumer perception and reality. Although the overwhelming part (90%) of participants stated to usually use the full capacity or even load the dishwasher in such a way that it is nearly overloaded, all ways of measuring the use of dishwashers' capacity (number of dishes, load weight, visual assessment of used space) indicate that in a relatively high number of cycles the dishwasher is not fully filled.

Firstly, as far as the analysis of the pictures of dishwasher loads is concerned the opposite of what the majority thinks of the loading appears to be true. Although in total around 35 % of the dishwasher baskets were fully or extremely filled and the majority of participating households loaded the baskets moderately (around 40 %), still about 20% of the baskets were found to be only slightly filled. For this share of loads it means that 40% and more of the baskets' space was left free. The converse argument would be that approximately every tenth dishwasher cycle could be saved when the dishwasher would be loaded to its full capacity. Particularly British participants loaded their dishwasher inefficiently because the share of slightly filled dishwasher racks was with around 45% considerably high and so the savings in the frequency of dishwasher cycles run could amount to around 22%.

Secondly, when the dishwasher capacity use is measured by the weight of the load, the findings of the visual assessment may be called to be approved. Based on the assumption made for the calculation of the load weight, none of the researched households reached the level of the reference, the weight of the EN50242 load (12 place settings = 23.9 kg). The arithmetic means of countries are only amounting to the half of this. The household with highest average load weight is with 18.3 kg still 22% lighter than the reference load.

In addition, when comparing the standard load for testing the performance of dishwashers to the loads observed in the households it gets obvious that the standard is lacking of consumer reality. Not only the number of items loaded into the dishwasher differs greatly from the currently used standard (in all of the researched countries the average dishwasher load contains less than half of the amount), but also the mixture of different materials in the reference load does not reflect common household loads. Especially the proportion of dishes made of plastics and wood (up to 11 %) is exemplary for this instance.

The lower load weight caused by items made of relatively light materials (such as plastics or wood) and of course the relatively low number of items per load in general has consequences on the energy consumption of the dishwasher. The presented experimental research confirmed that the energy consumption decreases when the load size is lowered.
By considering the actual weight of the observed household loads in the procedure of calculating the dishwasher's energy consumption an average reduction in dishwashers' energy use of around 6 % has been calculated. It must be stressed that although the total energy consumption decreases by lighter load weight, the degree of reduction in the energy use does not equal the degree of load weight reduction (on average -50 % compared to standard load). Consequently, the consumer causes a reduction of the energy efficiency of their dishwashers.

In order to achieve a higher degree of sustainability a change of consumer behaviour is necessary. This paper concentrated on the use of dishwashers and showed that consumer habits concerning the loading of the dishwasher can be optimised. But of course other areas of dishwashing in the households, such as the programme choice, the pre-rinsing of dishes before loading the machine and the extent of manual dishwashing, are as important for the efficiency of the whole dishwashing process, and hence must be considered too when consumer advice is developed.

References

[1] EN 50242 A1:2003. (2003) Electric Dishwashers for Household Use – Methods for Measuring the Performance. European Committee for Electrotechnical Standardization, Brussels.

[2] Zott A.; Hubbuch M. Durchschnittliche Verbraucherbeladung beim maschinellen Spülen. In: SÖFW Journal – Seifen Öle Fette Wachse, 2008, Vol. 132, No.1, 48 -55.

[3] Washing machines, driers and dishwashers. Background reports**.** Vol. 2: Experimental analyses linking energy and water consumption with performance. Group for Efficient Appliances, June 2005, ISBN 87-7844-016-5.

[4] Stamminger R. Preparatory studies for eco-design requirements of EuPs - Task 3-5 (Tender TREN/D1/40-2005). [WWW document]. URL http://www.ecowet-domestic.org/index.php?option=com_docman&task=cat_view&gid=27&Itemid=40 (accessed on 15 February 2009).

[5] Stamminger R. Preparatory studies for eco-design requirements of EuPs - Task 2 (Tender TREN/D1/40-2005). p. 86 et seq. [WWW document]. URL http://www.ecowet-domestic.org/index.php?option= com_docman&task=doc_view&gid=74 (accessed on 15 February 2009)

Washing Machines: Key Criteria for Best Available Technology BAT

Barbara Josephy, Eric Bush, Jürg Nipkow, Sophie Attali

Topten International Services (Paris, France)

Abstract

Washing machines will reveal new energy consumption results, because of changed standards for testing and labelling, new performance requirements, and because of the market penetration of “new” appliances.

For household laundry washing machines, the updated EU energy label and the Eco-design requirements entered into force by the end of 2010, while the EU measurement standards still are under revision.

Future key parameters of washing machines will be energy and water consumption both for full and partial loads, spin-drying efficiency, availability of a 20°C-cycle and supply for hot fill.

Topten, an independent international programme to create a dynamic benchmark for high-efficient consumer products, carried out a manufacturers’ inquiry on the key parameters of their new washing machine models ready to enter the market complying with the new EU energy label requirements. By means of these data Topten selected the actually best-performing household washing machines on the European market and presents them on www.topten.eu. This market research done by Topten in an early stage provides an important and helpful source for policy makers.

The paper outlines key parameters, best available technology, barriers and chances for better washing machines.

Introduction

Over the past few years the energy efficiency and the market penetration of efficient washing machines has increased. In Europe, the regulatory framework has evolved and the enforcement of new regulations for washing machines has started.

We firstly present the European regulations on washing machines (old and new EU Energy label, Eco-design requirements), and the criteria set by The Blue Angel and the EU Ecolabel. Subsequently the key parameters of washing machines are discussed, in particular those influencing energy efficiency, energy consumption and water consumption. The paper then presents the selection criteria of Topten for best performing washing machines available on the European market, the results of the Topten-inquiry with manufacturers on how their washing machines comply with the requirements of the new EU energy label and discusses conclusions for energy policies.

Definition

A household laundry washing machine (in the following washing machine) is understood as an automatic washing machine, which is designed to be used principally for non-professional purposes, which cleans and rinses textiles using water, and which also has a spinning function for water extraction [1].

Regulations

Revised EU Energy Label

The regulation of the EU energy label for washing machines recently has been updated. The new regulation entered into force in December 2010 and the new EU energy label must be shown on appliances from December 2011 [2]. During this transition period of one year, the old and the new EU energy labels can coexist. As shown in Table 1, the new EU energy label presents a number of differences compared to the old version:

Table 1. Differences between old and new EU energy label for washing machines

	Old EU Energy Label	**New EU Energy Label**
Rated capacity	kg at full load 60°C	kg at full load 60°C or 40°C, whichever is the lower
Cycles for the calculation of the Energy Efficiency Index, electricity and water consumption, remaining moisture content	60°C full load (cotton)	60°C full load (cotton) 60°C half load[1] (cotton) 40°C half load (cotton)
Energy consumption	kWh per cycle	kWh per year[2]
Water consumption	Litres per cycle	Litres per year[3]
Washing performance classes	A to G	Not indicated any more[4]
Energy efficiency classes	A to G: A ≤ 0.19 kWh/kg[5] B ≤ 0.23 kWh/kg C ≤ 0.27 kWh/kg D ≤ 0.31 kWh/kg Etc. Etc.	A+++ to D: A+++ EEI[6] < 46 A++ 46 ≤ EEI <52 A+ 52 ≤ EEI <59 A 59 ≤ EEI <68 Etc. Etc.
Spin-drying efficiency class	A to G[7]	A to G[8]

[1] Half load is measured in order to better reflect the use of washing machines in homes.

[2] Weighted annual energy consumption for washing (60°C full load (3x), 60°C half load (2x), 40°C half load (2x)) for 220 standard washing cycles, inclusively consumption for the left-on mode and off mode. Calculation details see Annex VII of [2].

[3] Based on 220 standard washing cycles, calculated in accordance with Annex VII of [2].

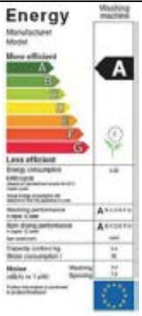
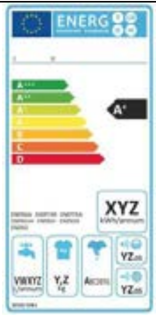
[4] For washing machines with a capacity > 3 kg minimum performance A is required (B for machines ≤ 3 kg), see below.

[5] 60°C full load cotton.

[6] The Energy Efficiency Index (EEI) shall be determined in accordance with Annex VII of [2].

[7] 60°C full load cotton.

[8] Weighted remaining moisture content in percentage (60°C full load (3x), 60°C half load (2x), 40°C half load (2x)) in accordance with Annex VII of [2].

Label		

Introduction of Eco-design Requirements

The preparatory study lot 14 for domestic washing machines and dishwashers was carried out to analyse the technical, environmental and economic aspects of washing machines (and dishwashers) [3]. Based on that, an Eco-design regulation for washing machines has been worked out, which entered into force in December 2010 [1], [4]. It sets minimum performance and information requirements on washing machines to be sold on the European market. An overview on requirements and the date, from when the requirements shall be applied, is given in Table 2.

Table 2. Overview on the Eco-design requirements for washing machines

	December 2011	June 2012	December 2012	December 2013
Energy Efficiency Index	EEI < 68 (all machines)			EEI < 59 (≥ 4 kg)
Washing Efficiency Index	> 1.03 (> 3 kg) > 1.00 (≤ 3 kg)			
Water consumption per cycle	≤ 5 x c + 35[9] (5 kg: 60 litres 6 kg: 65 litres 7 kg: 70 litres 8 kg: 75 litres 9 kg: 80 litres 10 kg: 85 litres)			≤ 5 x c/2 + 35[10] (5 kg: 47.5 litres 6 kg: 50 litres 7 kg: 52.5 litres 8 kg: 55 litres 9 kg: 57.5 litres 10 kg: 60 litres)
Generic requirements		Instruction manuals shall provide information on 60°C and 40°C cotton programmes, power consumption off/ left-on, programme time, remaining moisture content, energy and water consumption, recommendation on detergents.	For the calculation of the energy consumption and other parameters for washing machines, the cycles which clean normally soiled cotton laundry at 40°C and 60°C shall be used and shall be clearly identifiable.	Availability of a cold wash programme (max. 20°C)

The Eco-design requirements can be summarized as follows:

---

9 Where c is the rated capacity for 60°C or for 40°C at full load, whichever is the lower.

10 Where c1⁄2 is the rated capacity for 60°C or for 40°C at partial load, whichever is the lower.

- By the end of 2011 all washing machines must be at least of energy class A. This requirement will be strengthened to A+ for washing machines ≥ 4 kg by the end of 2013. In other words: washing machines below (new) energy class A will be banned from the market by the end of 2011.
- Minimum washing performance for washing machines > 3 kg corresponds to class A according to the old EU energy label.
- Limits are set for the water consumption and will be slightly strengthened by the end of 2013.
- All washing machines have to offer a cold wash programme (max. 20°C) by the end of 2013[11].

Requirements by The Blue Angel, the EU Ecolabel and Topten

Besides the Eco-design requirements outlined above, The Blue Angel and the EU Ecolabel (both environmental endorsement labels) as well as Topten set voluntary minimum criteria for washing machines.

The Blue Angel

Particularly energy-efficient and climate-friendly products are awarded by the well-known German Eco-label The Blue Angel[12]. The award criteria for washing machines are described in RAL-UZ 137 [5] and can be summarized as follows:

- Energy Efficiency Index: < 52
  (which corresponds to A++ and better according to the new EU energy label)
- Left-on mode: max. 3.0 Watt; Off mode: max. 0.5 Watt
- Water Consumption: max. 9 litres/kg
- Washing Efficiency Index: > 1.03
  (which corresponds to A according to the Eco-design requirements)
- Spin-drying efficiency: B or better
- Further requirements are made on the availability of a 20°C-programme, noise, the availability of (most important) spare parts, materials, water safety and instruction manuals.

EU Ecolabel

The European Ecolabel is a voluntary scheme that today covers a wide range of services and products[13]. The Ecolabel for washing machines is currently under revision[14]. Criteria will be set for:

- Energy Efficiency Index
- Water Consumption
- Washing Efficiency Index

---

[11] However it is not specified whether this programme should be for cotton and easy-care or just for wool or silk.

[12] For more information see http://www.blauer-engel.de/en/index.php

[13] For more information see http://ec.europa.eu/environment/ecolabel/

[14] At the closing date of this paper the revised EU Ecolabel for washing machines was not yet published.

- Spin-drying efficiency
- Further requirements are made on noise, flame retardants and heavy metals, prevention of excess use of detergents, appliance design, design for disassembly, user instructions, life time extension, information appearing on the Ecolabel and biocides.

Topten

Topten is an international online search tool which presents the most energy efficient products such as household appliances, office equipment, consumer electronics, building components, lamps and cars.

Topten-criteria are primary based on the EU energy label. Depending on the product group additional criteria are required. The Topten-criteria for highly efficient washing machines are listed in section "Best Performing Washing Machines of Europe". For more information on Topten see [6], [7].

Key Parameters of Washing Machines[15]

The most significant environmental aspects of washing machines are energy and water consumption in the use phase [1].

One measure to reduce the energy consumption is an effective load sensor. Further measures considerably reducing the energy consumption are the availability of a cold wash programme and hot water supply. Best spinning performance (with few remaining moisture content) is of high importance for the drier's energy consumption.

An effective load sensor reduces not only the energy consumption but also the water consumption. However, rinsing should be sufficient[16].

The common practice of users to over-dose detergents can be prevented by automatic dosage systems. Correct dosage of detergents raises the rinsing quality and reduces the amount of chemicals released to the environment.

The use of rainwater in washing machines can be an expedient and cost effective option. Depending on local water and sewage water tariffs and/or the water consumption of the washing machines, the water costs for washing machines may be as much as 50 to100% of the respective electricity costs.

Noise during washing and spinning can be disturbing, but this impact strongly depends on where the washing machine is installed and is more relevant in flats than in the cellar.

The following sections discuss energy efficiency, effective load sensor, spin-drying efficiency, availability of a cold wash programme and supply for hot water in more detail.

Energy Efficiency

Energy efficiency according to the new EU energy label is positively influenced by an effective load sensor which reduces energy consumption at partial load as well as by an optimised 40°C programme. The influence of the power consumption in left-on mode and off mode is secondary. The increase of energy efficiency is often connected to longer programme duration.

---

[15] See also [8].

[16] An EU standard allowing the measurement of the rinsing performance is in development.

Although the energy efficiency of washing machines still can be optimised, the development is relatively limited in the near future compared to other white goods such as refrigerators and freezers. Additional, but high energy saving potentials lay in a high spin-drying efficiency, the availability of a cold wash programme and the supply for hot fill.

Effective Load Sensor

Due to the trend towards larger washing machines (6 to10 kg) as well as the related problem of filling washing machines only partially, it is important that the washing machine has a sensor capable of estimating the weight of the laundry load and able to automatically adjust programme duration, energy and water consumption. Half load theoretically would lead to a reduction of 50% of electricity and water consumption compared to full load. In reality the reduction with load sensors might be about 20%. An effective load sensor positively influences the energy efficiency and in particular is meaningful for larger-sized washing machines (> 6kg), which are rarely fully loaded. Load control features should be accompanied by an eye-catching indication in case of failure, to prevent full-load setting as default for long periods.

Spin-drying Efficiency

As shown in Figure 1, moving from a washing machine with a spin-drying class B to one with a spin-drying class A saves three times more energy (in case that a tumble drier is used for drying) than moving from a washing machine with energy class A to one with (unofficial "old") energy class A+[17]. Thus the spin-drying efficiency is of high importance to the overall efficiency of the total laundering process.

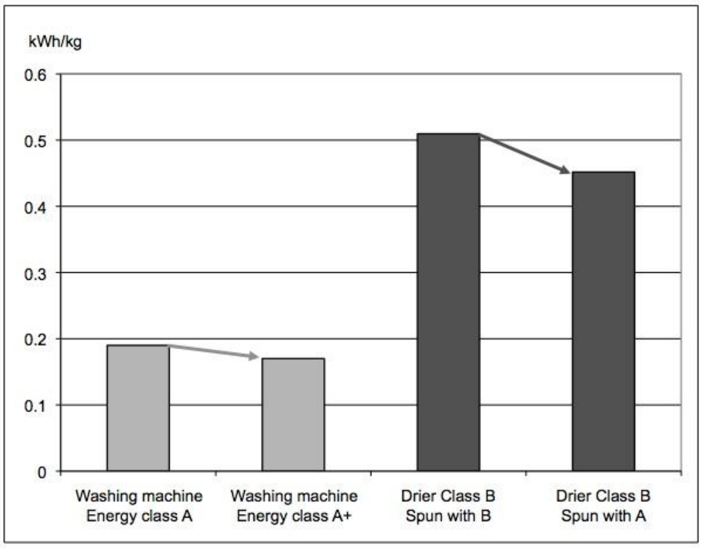


Figure 1. Energy consumption and energy savings per kg of laundry according to higher efficiency classes for washing and spinning (with drier class B), related to the old EU energy label, calculated by Topten[18].

---

[17] Classes according to the old EU energy label. The unofficial energy class A+ (< 0.17 kWh/kg) is a voluntary agreement between CECED manufacturers and the European Commission.

[18] 0.02 kWh/kg are saved by increasing the energy efficiency from 0.19 kWh/kg (A) to 0.17 kWh/kg (unofficial A+). 0.06 kWh/kg are saved by increasing the spin-drying efficiency from B to A (Washing machine with spin-drying efficiency class B = 52% initial moisture content, A = 44% initial moisture content; a drier with class B (a type that is still widespread in European households [9]) consumes 0.51 kWh/kg if the washing machines' spin-drying efficiency is B and 0.45 kWh/kg if the washing machines' spin-drying efficiency is A).

Availability of a Cold Wash Programme

The lion's share of washing machine electricity consumption is for heating water from the pipe temperature up to 30°C, 40°C, 60°C or even 90°C. Washing at lower water temperatures (max. 20°C) requires up to 70% less electric energy compared to 60°C.

In 2009, the Swiss retailer Migros was one of the first to develop and sell environmentally friendly detergents designed for low water temperatures. Environmentally friendly cold wash detergents then became a standard for producers within a very short time and are recognised as an innovation by the whole laundry industry sector[19].

Hot Water Supply

Hot water supply ("hot fill") for washing machines can be both economically and ecologically reasonable provided that the hot water is heated efficiently (e.g. by renewable energy sources, heat-pump-heating or district heating (e.g. from renewable energy sources or waste heat)) and that it is possible to appropriately install a warm water pipe [10], [11]. The higher the washing temperature, the higher the potential savings from hot water supply (up to 70% less electricity consumption by the washing machine). If the "hot fill" hot water is heated to 100% by an electric water heater, this (of course) does not bring any energetic benefits compared to direct warming in the machine. The technology is available on the European market, however, its practical use strongly differs within the European countries.

Market Development of Washing Machines

In 2005, 167 millions washing machines were installed in the EU-25 [3]. The market is mature and of substitution (not first equipment).

The current standard size of washing machines is 5 kg. There is a clear trend towards washing machines larger than 6 kg (up to 10 kg).

The old EU energy label for washing machines contains various performance values: energy and water consumption, washing performance and spin-drying performance (see above).

Since 2004, almost all new washing machines sold in Europe reach energy class A according to the old EU energy label (< 0.19 kWh/kg)[20] [9][21]. Many washing machines have an energy consumption of 0.17 kWh/kg and even less, claiming the old (unofficial) energy class A+.

In 2008, the spin-drying performance of the washing machines sold in Europe was mostly B and C [9]. This is insofar of high relevance as weakly spun laundry strongly increases the driers' energy consumption (see above).

The percentage of sold A-machines as well as the percentage of the spin-drying efficiency classes strongly differ within European countries [9].

---

[19] For further information on detergents see e.g. wfk detergency conference and articles in Chemical & Engineering News covering enzymes, phosphates, and other aspects.

[20] 60°C cotton.

[21] GfK-sales data for 8 representative EU-countries: Denmark, France, Germany, Italy, Netherlands, Poland, Portugal, United Kingdom and data from Swiss Association of the Domestic Electrical Appliances Industry FEA for Switzerland.

Best Performing Washing Machines of Europe according to the New EU Energy Label

Topten – "Best Products of Europe"

Topten presents on www.topten.eu the most efficient household appliances, office equipment, consumer electronics, building components, lamps and cars available on the European market ("Best Products of Europe") and thus is an important tool for policy design processes. For more information on Topten see [6], [7].

Topten-Inquiry with European Washing Machine Manufacturers

According to the old EU energy label for washing machines the declarations are based on a 60°C standard cotton programme with full load. With the new EU energy label also programmes with lower temperatures and partial load become relevant. Therefore the classification of the new EU energy label cannot directly be compared to the classification of the old label and will provide a new picture of the market of washing machines.

To map this new picture early in time, Topten conducted an inquiry with European washing machine manufacturers (12 brands). The objective was to present a list on www.topten.eu with the best performing washing machines available on the European market according to the new EU energy label.

As only aggregated values are declared on the new EU energy label and the declaration of the underlying values for the calculations is not required (e.g. energy consumption at 60°C full load, 60°C half load and 40°C half load, programme times etc., see [2]), manufacturers were asked to provide Topten also these values. Furthermore, they were asked to provide maximum spin speed and the availability of other features such as cold wash programme, hot/rainwater supply and automatic dosage system.

Topten Selection Criteria for Washing Machines

Topten designed stringent criteria to help finding the most efficient washing machines available on the European market.

In order to qualify for www.topten.eu washing machines must meet the following criteria:

- Energy efficiency class: A+++ according to the (new) EU energy label
- Spin-drying efficiency class: A according to the (new) EU energy label
- Washing efficiency class: A (is not declared on the new EU energy label because it is a requirement for all washing machines with a capacity of more than 3 kg, see above)
- Water consumption: maximum 12 litres per kg laundry, calculated as follows: annual water consumption according to the declaration on the EU energy label in litres divided by the annual amount of washed laundry in kg (220 cycles).
- Available in at least one European country.

Additionally suppliers have to provide Topten with the following data:

- Energy Efficiency Index
- Energy consumption per cycle in kWh for 60°C full load, 60°C half load and 40°C half load
- Programme duration for 60°C full load, 60°C half load and 40°C half load

- Power consumption of left-on mode and off mode
- Availability of a 20°C-programme for cotton
- Maximum spin speed
- Availability of a water protection system (Aqua Stop, waterproof, water control system etc.)

The selection criteria will regularly be updated according to market development.

Best Performing Washing Machines of Europe

Figure 2 shows the best performing washing machines of Europe according to the Topten-criteria.

Brand	Miele	Miele	Miele	Miele	Miele	Miele	Miele	Miele
Model	W SPECIAL S3	W 19-79	W 58-25	W 59-05	W 58-41	W 67-69	W Supertronic	W 59-69
Costs for electricity and water (€/15 years)	787	787	787	787	787	787	880	880
Capacity (kg)	7	7	7	7	7	7	8	8
Energy efficiency class	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++
Energy Efficiency Index	41.9	41.9	41.9	41.9	41.9	41.9	42.5	42.5
Spin-drying class	A	A	A	A	A	A	A	A
Energy (kWh/year)	160	160	160	160	160	160	182	182
Energy (kWh/cycle) 60 / $60_{1/2}$ / $40_{1/2}$	0.8 / 0.66 / 0.58	0.8 / 0.66 / 0.58	0.8 / 0.66 / 0.58	0.8 / 0.66 / 0.58	0.8 / 0.66 / 0.58	0.8 / 0.66 / 0.58	0.91 / 0.76 / 0.66	0.91 / 0.76 / 0.66
Water (litres/year)	10780	10780	10780	10780	10780	10780	11880	11880
Programme time (min) 60 / $60_{1/2}$ / $40_{1/2}$	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119	179 / 149 / 119
Left-on/off (W)	0.75 / 0.2	0.75 / 0.35	1.0 / 0.35	1.0 / 0.35	1.0 / 0.35	1.5 / 0.15	1.5 / 0.2	2.25 / 0.15
Max. spin speed (rpm)	1600	1600	1600	1600	1600	1600	1600	1600
20° C for cotton	yes	yes	yes	no	yes	yes	yes	yes
Hot/Rain water supply	no / no	no / no	no / no	no / no	yes / yes	no / no	no / no	no / no
Countries available	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand

Figure 2. Best performing washing machines of Europe presented on www.topten.eu (7kg and 8 kg, Screenshot, 6th May 2011)

At the closing time of this paper already first washing machines (Miele) comply with the stringent Topten-criteria. The list on www.topten.eu will be amended as soon as complying products are available on the European market.

The Energy Efficiency Index of the listed washing machines is 41.9 (for 7 kg-machines) and 42.5 (for 8 kg-machines) respectively. This exceeds the threshold for the A+++-class (EEI < 46) by 9%.

Miele has developed its 7-kg models further (they still have the same model names) and has reduced their energy consumption for 60°C full load by 24% from 1.05 kWh/cycle to 0.8 kWh/cycle.

The listed washing machines consume at 60°C half load about 17% less energy than for washing at 60°C full load[22].

All of the listed machines reach best spin-drying efficiency class (A)[23]. Maximum spin speed is 1600 revolutions per minute.

Seven of the eight listed models offer already a cold wash programme for cotton.

One of the listed washing machines offers a hot water supply and thus allows to benefit of renewable energies (e.g. solar water heaters).

It is worth underlining that Miele already publishes detailed data in its catalogues (e g. energy consumption at different loads and temperatures, power consumption in left-on and off-mode, programme times etc.).

Discussion

A high energy saving potential of washing machines lies in a further reduction of the energy consumption at half load (theoretically 50%; in practice about 20%, which in fact leads to an increase of the energy consumption per kg laundry). An effective load control positively influences the energy efficiency and in particular is meaningful for larger-sized washing machines (> 6kg), which are seldom fully loaded.

It is feasible to reach the best Energy Efficiency class as well as the best spin-drying efficiency class. It seems that to manufacturers with an interest to produce highly efficient washing machines both aspects – energy efficiency and spin-drying efficiency – are important.

The Eco-design regulation accounts for the high energy saving potential of cold wash and requires a 20°C-programme after December 2013. However it is not specified for which type of laundry this programme should be designed. Best-performing washing machines are already equipped with this feature for cotton (and not just for wool or silk for which such “gentle care” programmes are anyway often available).

Conclusions: Policy Discussion

Revision of the New EU Energy Label

The introduction of new energy classes (A+ to A+++) obviously encouraged industry to improve their machines. This shows that revising label classes strongly stimulates industry to develop and bring onto the market more efficient products and demonstrates further the key impact of updated labels.

However, a good part of the efficiency potential seems not to be used by the new labeling scheme for washing machines. As some washing machines already exceed the threshold of the best class by 9% there seems to be no incentive for further developments. The new energy efficiency classes are too weak, it is necessary to revise the EU energy label as soon as possible to facilitate further improvements. The top classes then should be held empty for future technical developments.

---

[22] The energy consumption values for the different loads and temperatures are measured values according to the drafted revised EN 60456.

[23] The thresholds for the spin-drying efficiency classes are identical between the old and the new EU energy label, but the calculation has changed (old label: remaining moisture content (in %) at 60°C full load; new label: weighted remaining moisture content (in %) at 60°C full load (3 x), 60°C half load (2 x), 40°C half load (2 x), in accordance with Annex VII of [2]).

Revision of the Eco-design Requirements for Washing Machines

It is recommended to revise the Eco-design Requirements for Washing Machines as soon as possible, in particular to strengthen the requirements on the Energy Efficiency Index. Additionally it is key that Minimum Energy Performance Standards (MEPS) shall also be set for the spin-drying efficiency (A is recommended). Drying laundry by tumble driers consumes far more energy than the washing itself and spinning is much more efficient than tumble drying.

Revision of The Blue Angel RAL-UZ 137 and the EU Ecolabel

The Blue Angel designed its criteria for RAL-UZ 137 at a date where no data was available according to the new EU energy label. The revised EU Ecolabel is not published so far. Both labels should focus on best products and therefore should – based on the results outlined above – revise/design their requirements as soon as possible, in particular regarding the Energy Efficiency Index and the spin-drying efficiency (A is recommended).

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission's Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in two more European countries (www.topten.eu).
- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.
- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation – www.repic.ch) and SECO (State Secretariat for Economic Affairs – www.seco.admin.ch) who supports the build-up of Topten China.

References

[1] European Commission. Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for household washing machines. In: Official Journal of the European Union, 11. 11. 2010.

[2] European Commission. Commission Delegated Regulation (EU) No 1061/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of household washing machines. In: Official Journal of the European Union, 30. 11. 2010.

[3] ISIS, 2007, Preparatory Studies for Eco-design Requirements of EuPs (Tender TREN/D1/40-2005) – LOT 14: Domestic Washing Machines and Dishwashers, www.ecowet-domestic.org

[4] European Commission. Corrigendum to Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for household washing machines (Official Journal of the European Union L 293 of 11 November 2010). In: Official Journal of the European Union, 16. 11. 2010.

[5] RAL-UZ 137. *Vergabegrundlage für Umweltzeichen: Waschmaschinen für den Hausgebrauch*, Der Blaue Engel, Juli 2009

[6] www.topten.eu – Best Products of Europe

[7] www.topten.info – International Platform for Best Products

[8] Josephy B., Bush E., Nipkow J., Attali S., Werle R., Granda Ch. *Changing washing machines and driers: Let's have a look at the laundry room.* Paper for the 2011 Summer Study of the European Council for an Energy Efficient Economy. 6-11 June 2011.

[9] Attali S., Bush E., Michel A. *Factors influencing the penetration of energy efficient electrical appliances into national markets in Europe.* Report for Defra / the Market Transformation Programme by SoWatt and Bush Energie GmbH, Paris, June 2009.

[10] Bush E., Jürg Nipkow J. *Energie- und Kostenoptimierungen bei Waschmaschinen und Geschirrspülern: Kriterien für Warmwasseranschluss.* Im Auftrag des Amts für Hochbauten der Stadt Zürich, 2005.

[11] Nipkow J., Bush E., Josephy B. *Schlussbericht 2007: Warmwasseranschluss*, 2007.

Energy Efficient Cooking – The EffiCooker

Jørgen Schjær-Jacobsen

Dept. of Civil Engineering, The Technical University of Denmark

1 Abstract

Substantial energy savings in moist heat cooking may be achieved by employing a pan with integrated electric heating element rather than an ordinary pan on a conventional electric range. The electric pan should be thermally insulated and equipped with an "intelligent" controller and timer. A working prototype of a saucepan, dubbed the EffiCooker, has been constructed according to these guidelines.

The EffiCooker has demonstrated energy savings in the range from 28% to 81% compared to conventional equipment when performing ordinary cooking tasks. The user need not be particularly aware of energy conservation to realize such savings; even those who are more concerned with their culinary achievements than with energy efficiency are likely to benefit.

Besides being energy efficient the EffiCooker is user friendly. Many cooking tasks, once initiated, are performed automatically without any further user attention.

The EffiCooker also may replace many other kitchen appliances, e. g. steamer, rice cooker, double boiler, chocolate melter, deep fat fryer, etc.

Keywords: Energy Efficient Cooking, Energy Conservation, Saving Energy

2 Moist or dry heat

When food is heated in a container in the presence of ample water, and ample heat is applied, then the temperature will stabilize at the boiling point of water (100°C for pure water at normal atmospheric pressure). The temperature cannot rise above the boiling point because the surplus energy will be expended evaporating water. This so-called *moist heat* cooking is an easy, if energy-inefficient, way of achieving a constant, well-defined temperature; it has probably been used ever since our ancestors learned how to make suitable cooking vessels. In this work we concentrate on this kind of cooking heat.

In the absence of free, liquid water (cooking with *dry heat*) the temperature may rise above that of the boiling point. Such temperatures are necessary to obtain *browning* of the food.

Boiling is cooking food immersed in boiling liquid, usually water. Heat is transferred to the food through convection in water. In *steaming* the food is not covered by water; instead heat is transferred from boiling water to food in a closed container by steam. As the temperature approaches the boiling point the space above the water is almost entirely filled with vapor, most of the air being expelled. The *steaming temperature* must be maintained slightly below the boiling point; this ensures that little steam will escape, provided the lid is reasonably tight-fitting. It also means that a slightly longer cooking time will be required, compared to boiling. In the EffiCooker, described later, the steaming temperature is fixed at 95°C, and the measured steam emission is approx. 7 g/h, corresponding to 4 W.

Steaming may be carried out in an ordinary covered pan, with just a minimal amount of water at the bottom. The food may be placed on a perforated steam plate or basket, or it may rest directly on the pan bottom. For types of food that do not "cling" to the pan bottom it is of no practical consequence whether the food is partly submerged or not. It follows that much less water is needed for steaming than for boiling; this may lead to substantial savings of time and energy, simply because less water has to be heated. Besides, the cooking water ends up being more concentrated and better suited for sauce making, even if less nutrients are leached from the food.

In some cases steaming is not feasible, for example if the food must be cooked in salted water, or if it is supposed to absorb much water, like rice or pasta, or for the preparation of soup or stew. Otherwise steaming should be preferred to boiling.

When using an ordinary cooking surface the heat setting must be manipulated manually. A high initial setting is necessary to accomplish fast boil-up, then the heat must be lowered to maintain just the right degree of boiling. Turning down the heat too late, or selecting a too high setting for continued boiling, will cause waste of energy through excessive evaporation; conversely, if a too low setting is selected the food may not be done as expected. Even for a careful user it may prove difficult to administer the heat setting properly, i.e. getting the food done without undue waste of energy. Also one must monitor the process closely to determine when the correct cooking temperature has been reached, in order to achieve correct timing. In the EffiCooker these problems have been solved by the automatic control, resulting in substantial energy savings for the careless user, too.

For a more thorough description of these and the following items see [1].

3 Saving Energy

Heat lost during (indoor) cooking is not always completely lost. In the heating season it may be put to good use heating the house, although it probably represents a higher quality form of energy than does that used for space heating. Conversely, in the cooling season it incurs an extra load on the air-conditioning system. Heat loss is often accompanied by vapor emission, which may contribute undesirably to the indoor air humidity.

Heating by induction or microwaves eliminates some of the heat losses mentioned above, but incurs an additional loss inherent in the conversion of electricity to high frequency. The resulting energy efficiency may be comparable to that of conventional methods. It will probably improve with future technological advancements.

The following applies to moist heat cooking in an ordinary pan on an electric cooking surface with resistance heating. These measures may be taken to improve the energy efficiency of the pan:

- Integrate heating element in pan
- Insulate pan
- Equip the pan with an "intelligent" power control that minimizes heat loss and assists the user in adopting energy efficient cooking practices

4 EffiCooker: The Electric Pan

An electric pan, dubbed the "**EffiCooker**" (**Effi**cient **Cooker**), has been constructed according to the above. It features thermal insulation, integrated heating element, and an "intelligent" controller and timer.

4.1 Construction

The prototype has been realized in the form of two parts: the pan proper and a "docking station" or base, that holds the controls; of course other configurations might be considered.

The pan prototype, shown in section view in Figure 1, is made out of two ordinary stainless steel pans, the smaller one fitted inside the larger one, so as to form a double-wall vessel. The two are bonded together along the rim using a silicone sealant. The "double-glazing" lid consists of two ordinary transparent lids glued together along the edge, also using silicone. In mass production some other bonding method, like welding, should be employed, so as to make the pan dishwasher-safe. The useful capacity is 1.7 L.

The heating element is a resistance filament encapsulated in a meander-shaped stainless steel tube. It is brazed onto the outside of the bottom of the inner pan and so conveniently concealed within the air space between the two pans. It would have been a good idea to sandwich a heat-distributing plate of e. g. copper or aluminum between the pan bottom and the heating element, but this has been left out in the present prototype. In mass production other types of heating element, e. g. a foil type, might be considered, that afford a more even heat distribution.

The dual-wall construction is used in order to reduce thermal losses. We shall show later that losses are reduced by more than 50%. In addition, it makes for easier handling, because the outer surfaces are kept cool to the touch. For example, one needs no kitchen mitts to drain the water from the vegetables. The insulation properties might have been further improved by vacuum or by some sort of insulation in the gap between inner and outer pan.

The protruding ends of the heating element form an electrical power connector on one side of the pan. Adjacent to it is a connector for carrying the temperature measurement signals (not shown in the

Figure 1. Section view of EffiCooker

drawing). It is important that the user keep the connector clean and dry when in use in order to avoid short circuits.

The base unit accommodates the cooker when in use. The unit contains electronic controller, display, and control knobs. When the cooker is placed in operating position on the base (Figure 2, center), its connector makes contact with a matching connector on the base. In the figure the two controls are visible in front, and behind the cooker is the rear panel with display.

Figure 2. EffiCooker flanked by rice cooker (left) and ordinary pan

4.2 Electronic controller

The electronic controller resides inside the base. It consists of a microprocessor and various input/output circuits, an LCD (**L**iquid **C**rystal **D**isplay), and two control knobs, both serving as rotating dials and as pushbuttons.

The controller determines the amount of electric power to be supplied to the heating element, based on the function selected by the user and the temperature inside the pan. It also works as a timer to end the cooking process once the predetermined cooking time is up.

One control knob facilitates selection of *boiling, steaming*, or a certain *temperature*. When *boiling* is selected the controller aims at a gentle boil, maintaining the temperature of the food at the boiling point. When *steaming* the controller attempts to maintain the *steaming temperature*, i.e. the temperature of the vapor above the water surface, at 95°C. In both *Boil* and *Steam* there are 9 settings that control the maximum power of the heating element during warm-up. E. g. to scald milk a low setting should be selected in order to avoid scorching but still end up at the boiling point. *Temperature* settings are used when not boiling or steaming. E. g. to slow-cook a stew one might set the temperature at 80°C in connection with a time of several hours. For deep fat frying a temperature of 180°C might be selected. Pushing the power button turns the power on or off.

Whether boiling, steaming, or temperature is selected, the controller provides tight regulation of the power delivered to the heating element, keeping energy consumption to a minimum. High power is applied at the beginning to accomplish fast boil-up. Boiling over is prevented, and in case of boiling dry the power is shut off.

The scheme for boiling and steaming is designed for a boiling point in the range of 98°C...102°C, i.e. cooking at sea level with only modest concentrations of solute in the water. In its present form it will not work at reduced pressure (high altitudes) or increased pressure (pressure cooker). For such applications modifications of the controller will be necessary.

The other control is the *timer* setting. The selected cooking time, shown on the display, may be adjusted whenever you want, even during countdown. The timing starts automatically once the required condition (steaming, boiling, or the selected temperature) is satisfied, so it metes out the actual cooking time accurately. The timer may also be started or stopped manually by pushing the button. The selected time as well as the elapsed and the remaining time are shown on the display. When the time expires an acoustic signal is emitted, and shortly before that the power is turned off. Usually no user attention is required once the process is started.

4.3 Versatility

Due to its good thermal properties and "intelligent" control the EffiCooker doubles as a

- Steamer
- Rice cooker
- Double boiler
- Deep fat fryer
- Egg cooker
- Chocolate melter
- Slow cooker ("Crock-pot")
- Pressure cooker (requires further development)

Many cooking tasks may be carried out automatically. Once started, no further user intervention is required. Tasks that are easily carried out, in addition to common cooking, include

- Scalding milk
- Reducing
- Thawing frozen food
- Reheating food
- Keeping food warm

The thermal insulation provides for easy handling: No oven mittens are required to drain the water from the vegetables. If one can tolerate a pan on the dining table it may be used for serving; the food will stay warm longer.

4.4 Cost

The EffiCooker will be more expensive than the simpler appliances that are on the market. The price depends very much on the production batch size. A rough guess based on the price of available appliances of more or less comparable complexity would be a US retail price of $150...300, corresponding to kr. 1500...3000 in Denmark, for a set of one pan and one base.

The simple payback period in Denmark for such a set may be calculated assuming the following conditions, not taking into account the appliances that it may replace

Retail price = 2200 kr.

Daily energy saving = 100 Wh = 0.1 kWh

Electrical energy price = 2 kr./kWh

Payback period = $\dfrac{2200}{0.1 \times 2 \times 365} \approx$ 30 years

Obviously one shouldn't buy the EffiCooker based solely on the payback period. Because of its versatility, energy efficiency, and user friendliness, however, the price and payback period are considered to be justified.

5 Energy Consumption

5.1 Testing Standards for Cooking Equipment

Most test procedures for cooktops are based on measuring the amount of energy required to raise a metal test block from room temperature to a specified higher temperature, or to boil a specified amount of water.

Existing testing standards, as far as is known, don't facilitate the comparison of the efficiency of an electric pan with that of an ordinary pan, nor the comparison of energy consumption when performing actual cooking tasks. In this treatment we mainly compare steady-state consumption and actual cook-

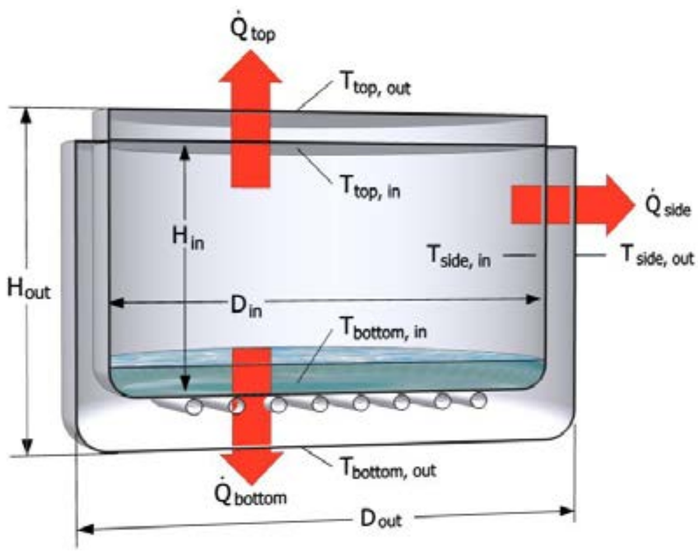


Figure 3. Simplified section view of EffiCooker showing three principal heat flows

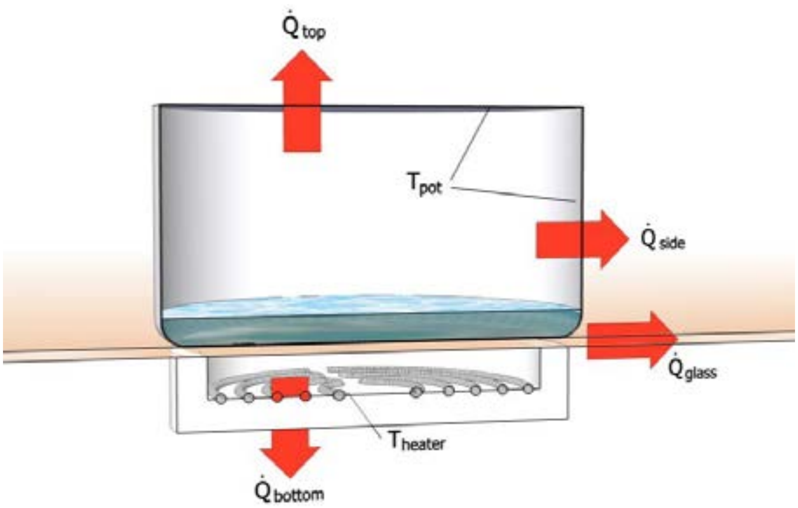


Figure 4. Simplified section view of conventional pan on electric kitchen range showing four principal heat flows

ing tasks.

5.2 Steady-State Energy Consumption

The total steady-state (i.e. at stabilized temperatures) heat losses for the EffiCooker and the ordinary pan have been measured when steaming at 95°C. The total losses are split into theoretical shares of losses from the top, side, and bottom, and in the case of the ordinary pan also heat conducted laterally through the glass-ceramic panel. These are called $\dot{Q}_{top}$, $\dot{Q}_{side}$, $\dot{Q}_{bottom}$, and $\dot{Q}_{glass}$, respectively.

Figure 3 is a simplified section view of the EffiCooker. Figure 4 is a similar view of a conventional pan sitting on an electric glass-ceramic cooking surface; beneath the panel is the bowl-shaped heater carrier, made of insulating material; the heating element is fitted in a groove in the carrier. The above-mentioned heat flows are shown in the figures.

The measured steady-state EffiCooker and ordinary pan convection and radiation heat losses when

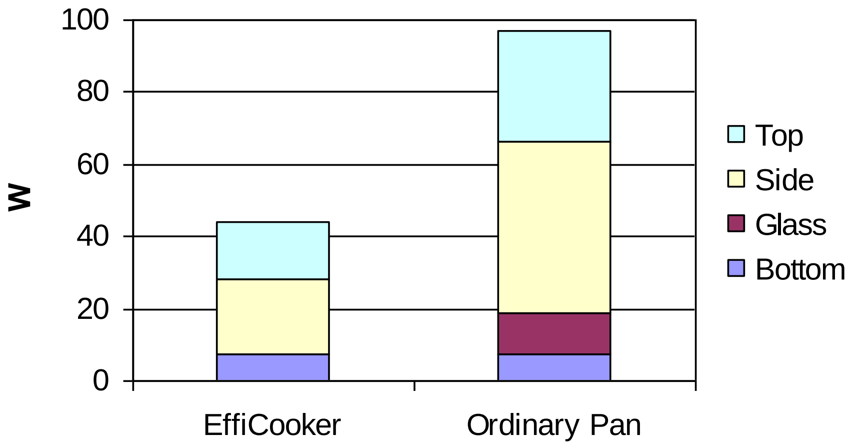


Figure 5. Steady-state energy losses steaming at 95°C

steaming at 95°C are shown in Figure 5, also showing the shares of Top, Side, Glass, and Bottom losses. The EffiCooker loss (44 W) is about 55% less than that of the ordinary pan (97 W).

5.3 Boiling water

The process of heating water to the boiling point is often used as a means of describing the energy efficiency of cooking equipment, as it is rather well defined, although in the case of manual control there may be some uncertainty regarding the exact moment to turn the power off. Figure 6 shows the results of boiling 1 kg water in the EffiCooker, in an electric kettle, and in a conventional pan on a glass-ceramic range. The initial water temperature is 15°C.

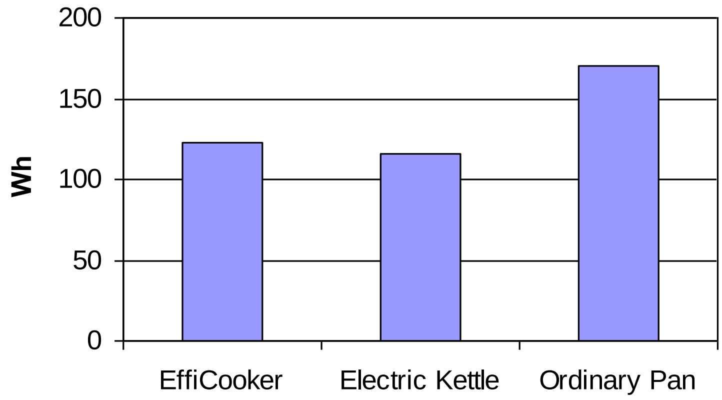


Figure 6. Energy consumptions boiling 1 kg water

The electric kettle performs slightly better than the EffiCooker. At 116 Wh it saves 32% compared to the ordinary pan (170 Wh), whereas the EffiCooker (123 Wh) saves 28%. The nominal power of the electric kettle (2200 W) is about twice that of the EffiCooker (approx. 1100 W), which of course makes the electric kettle faster and also may account for the slightly higher efficiency. So for heating water the electric kettle is the better alternative.

5.4 Soft-cooked eggs

This subject will be treated in some depth because it is an example of a rather critical process regarding time and temperature, and because it proves how efficiently and effortlessly it is handled by the EffiCooker.

To soft-cook an egg, i.e. to end up with a firm white and a runny yolk, the egg is usually placed in hot water or steam for a certain time. The temperature at the white-yolk interface should ideally reach about 67°C.

The formula below gives the time t_{cooked} needed to obtain the temperature T_{yolk} at the outer boundary of the yolk, from the moment the egg is plunged into the hot water. The parameters of the formula are given with typical values [3].

$$t_{cooked} = \frac{m^{\frac{2}{3}} c_p \rho^{\frac{1}{3}}}{k\pi^2 (\frac{4}{3}\pi)^{\frac{2}{3}}} \ln\left(0.76 \times \frac{T_{egg} - T_{water}}{T_{yolk} - T_{water}}\right) \text{ [s]}$$

T_{egg}	initial temperature of egg = 6°C
T_{water}	temperature of hot water or steam = 100°C boiling, 95°C steaming
T_{yolk}	desired temperature at yolk outer boundary = 67°C
m	mass (weight) of egg [g]
ρ	density of egg = 1.038 g/cm^3
c_p	specific heat of egg = 3.7 J/(g·K)
k	thermal conductivity of egg = 0.0054 W/(cm·K)

According to the formula the cooking time for a 64 g egg will be about 6 minutes if boiling at 100°C and 6.5 minutes if steaming at 95°C. We compare the EffiCooker with the conventional range preparing two soft-cooked eggs of 64 g each. In this example we try to imitate a user who is more concerned with getting the eggs cooked right than with energy conservation. Such a user is believed to use ample water, ensuring more exact timing with less attention.

The eggs are placed in the EffiCooker along with 50 g water, covered. Because of the automatic timing even the prodigal user sees no reason to add more water. "Steam 8", "6:30" are selected, and the power turned on. At the sound of the beep the eggs are removed, chilled briefly, and served.

In the case of the kitchen range an ordinary pan of capacity similar to the EffiCooker is filled with 1 kg water, enough to just cover the eggs. The pan is covered and the water brought to a boil at maximum heat setting. The eggs are slipped in, the lid replaced, and the timer started. After one minute, when the water has returned to a rapid boil, the heat is turned down to just keep the water boiling. One minute before the eggs are done the heat is turned off. After 6 minutes of immersion the eggs are taken up, briefly chilled, and served.

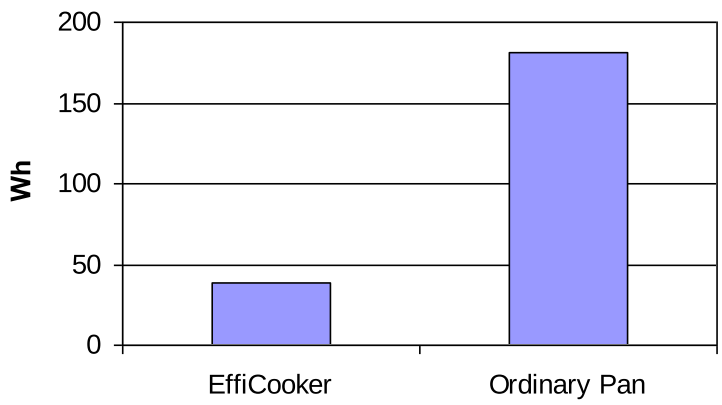


Figure 7. Energy consumptions preparing 2 soft-cooked eggs

The results are compared in Figure 7. Employing the EffiCooker results in a saving of energy of 78% (39 Wh versus 181 Wh). It also saves time (8 minutes versus 19 minutes).

5.5 Boiling pasta

Dry pasta is cooked in boiling water to a standard called "al dente", meaning it should be tender but not too tender. During cooking it absorbs water corresponding to approximately 1.5 times its own weight. Consequently steaming cannot be employed.

It is a persistent notion that pasta should be cooked in an overly large amount of rapidly boiling water, not covered, to keep it from sticking. For example, Joy of Cooking [2] states "7 quarts of rapidly boiling water for a pound of pasta", which corresponds to an amount of water that is 15 times that of pasta by weight. This looks like a striking example of squandering energy; using this method leads to an energy consumption more than five times greater than that of the EffiCooker. An experiment cooking 200 g pasta shows that excellent results may be obtained using much less water, about 3.5 times the weight of the pasta. Besides the EffiCooker we try two cooking methods using an ordinary pan: the "Joy of Cooking" and an ordinary method using less water. The dry pasta at hand is labeled "Cooking time 9...11 minutes".

EffiCooker: Put 200 g dry pasta and 700 g water into the EffiCooker and cover. Select "Boil 7" and "10 m" and turn the power on. At the sound of the beep the pasta is ready. The excess water may be conveniently drained from the pasta by holding the lid askew. This may be done with one's bare hands, because the pan and lid are thermally insulated. If the pasta is served in the cooker it will keep warm for a long time.

Joy of Cooking: Bring 3000 g water to a rapid boil. Add 200 g dry pasta. Reduce heat to maintain rapid boil. Don't cover. When pasta is al dente turn heat off and remove the pasta from the water with a pasta scoop.

Ordinary pan: Put 200 g dry pasta and 700 g water into the pan and cover. Turn the heat to maximum; when boiling start timer and reduce heat to maintain boil. After 9 minutes of boiling turn heat off. After an additional minute scoop up pasta or use a colander.

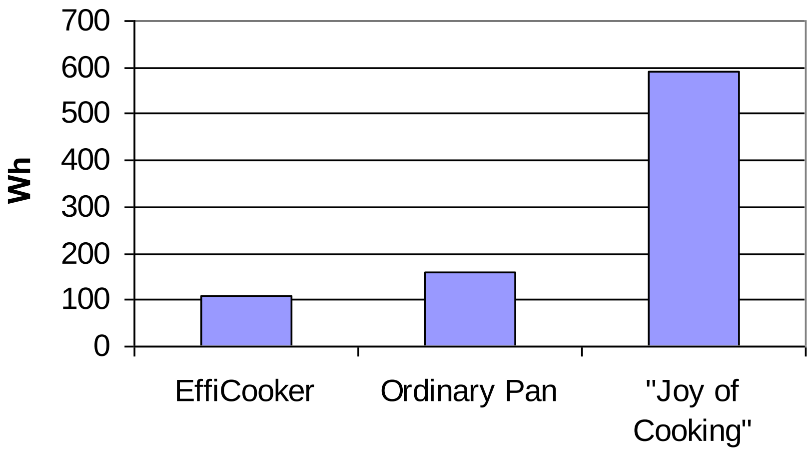


Figure 8. Energy consumptions boiling 200 g pasta

The results in Figure 8 show the substantial energy consumption caused by the "Joy of Cooking" method (590 Wh) over those of the ordinary method (160 Wh) and the EffiCooker (110 Wh). The saving obtained with the EffiCooker over the Joy of Cooking method is 81%. Over the ordinary method it is 31%.

5.6 Steaming potatoes

The EffiCooker is compared to an ordinary pan steaming 1 kg potatoes using 100 g water, as expected by a user who takes an interest in energy consumption. In Figure 9 the energy consumptions are compared. In the case of the EffiCooker there is an energy saving of 30% (132 Wh versus 190 Wh).

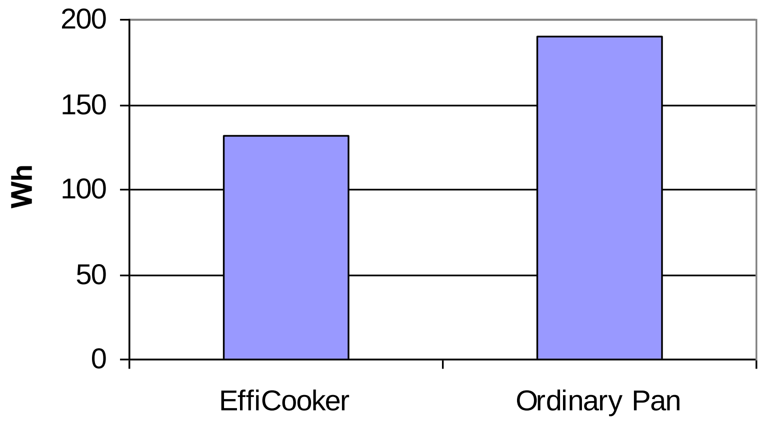


Figure 9. Energy consumptions steaming 1 kg potatoes

5.7 Boiling rice

A rice cooker is an appliance that automatically controls the heat and timing. It is primarily meant for cooking rice, as the name implies, but may also be employed for other kinds of food. Once the user has loaded the ingredients into the rice cooker and turned the power on, the food is supposed to be cooked with no further attention.

Rice cookers come in various degrees of sophistication. A simple type is very popular, especially in Asian countries. The automatic timing is based on the time it takes water to partly be absorbed in the food, partly evaporate, so the more water is added, the longer the cooking time. Therefore it is important to correctly estimate and measure the required amount of water. The power rating of the heat-

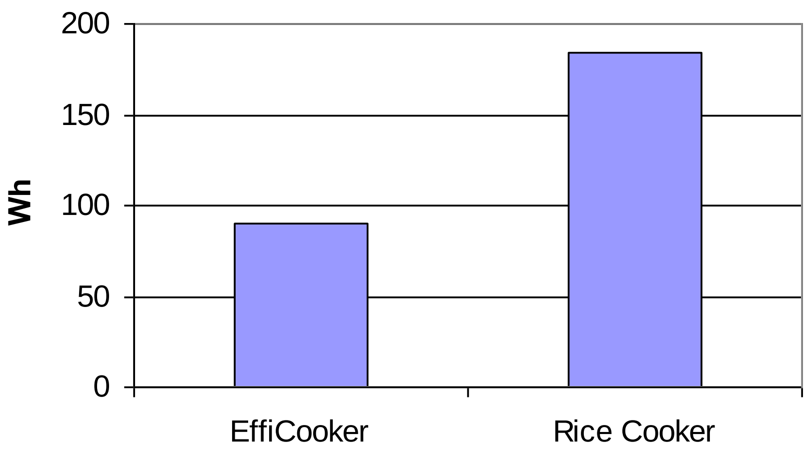


Figure 10. Energy consumptions boiling 200 g rice

ing element must be sufficient for a reasonably fast heating of the food and water, so boiling will be rather rapid, as it takes place at this same power level. Thus a relatively large amount of water is evaporated, resulting in low energy efficiency, and a tendency to boiling over. Besides a crust may form at the bottom, where the rice is heated above the boiling point.

In this experiment we compare the EffiCooker with the Tefal Classic 2.0 L (Figure 2, left), which is representative of the simple type of rice cooker, boiling 200 g of ordinary long-grain, white rice.

In the EffiCooker 440 g water (= 2.2 times the amount of rice by weight) is poured over the rice. "Boil 7" and "20 m" are selected and the power turned on. After ca. 30 minutes the audible signal sounds and the rice is ready to serve.

In the rice cooker 500 g water is added to the rice. The switch is moved to the "cook" position. After 23 minutes the rice cooker switches to "keep warm" and the rice is ready to serve.

The rice cooker is faster than the EffiCooker by 7 minutes but uses about twice as much energy (184 Wh versus 90 Wh), see Figure 10.

6 Conclusion

A working prototype of an electric saucepan, dubbed the EffiCooker, has been constructed. It features integrated heating element, thermal insulation, and an "intelligent" controller and timer.

The EffiCooker has demonstrated energy savings in the range from 28% to 81% compared to conventional equipment when performing ordinary moist heat cooking tasks. Even users who are more concerned with their culinary achievements than with energy conservation are likely to realize such savings.

Besides being energy efficient the EffiCooker is user friendly. Many cooking tasks, once initiated, are performed automatically without any further user attention.

The EffiCooker may replace many other kitchen appliances, e. g. steamer, rice cooker, double boiler, chocolate melter, egg cooker, deep fat fryer, slow cooker, etc. In addition to ordinary cooking the EffiCooker performs such tasks as scalding milk, reducing, thawing frozen food, and keeping food warm.

The energy efficiency, versatility, and user friendliness are considered to justify a rather high price and long payback period.

7 References

[1] Jørgen Schjær-Jacobsen: *Energy Efficient Cooking – The EffiCooker*, Dept. of Civil Engineering, The Technical University of Denmark, Report R-215, 2009, http://www.byg.dtu.dk/upload/institutter/byg/publications/rapporter/byg-r215.pdf

[2] Rombauer, Irma S., and Marion Rombauer: *Joy of Cooking*, Scribner, 1995.

[3] Williams, Charles D. H.: *The Science of Boiling an Egg*, University of Exeter, http://newton.ex.ac.uk/teaching/CDHW/egg/ originally in New Scientist magazine, April 4, 1998.

Energy efficiency in daily food preparation

Claudia Oberascher

HEA – Fachgemeinschaft für effiziente Energieanwendung e.V.

Christiane Pakula, Rainer Stamminger

University of Bonn, Household Appliance and Technology Section

Abstract

The great progress in the energy efficiency of household appliances is primarily generated by the improved design of refrigerators, freezers, washing machines and dishwashers. In the long term, a positive effect on the household electricity consumption is expected with increasing numbers of old appliances being replaced by new and more energy-efficient ones. Studies on electricity consumption of private households show that energy efficiency can also be improved by changes in the consumer behaviour, in addition to improvements in the technical design of appliances. Consumer studies on behavioural aspects of electricity consumption related to large household appliances have already been conducted, but only little information is available about cooking. However, the influence of consumer behaviour on energy consumption is particularly interesting where cooking is concerned. The most important processes of manual and machine food preparation shall therefore be investigated regarding performance and energy efficiency. This provides a basis for attempting to estimate the energy saving potential of optimised cooking processes for the most typical and relevant cooking processes in private households in Europe which are:

A: Boiling water. Representing hot drinks, soups and parboiling process.

B: Brewing coffee. Representing automated brewing processes.

C: Cooking potatoes. Representing the cooking process itself.

D: Boiling eggs. Representing automated boiling processes.

The study shows that the energy consumption of typical household cooking processes varies greatly according to the chosen method. In the tests carried out for this study, the method making most sense in terms of energy consumption saved between 50 and 70% energy compared to the least favourable method. Based on the results, the authors provide recommendations on energy saving cooking methods.

Introduction

Rising living standards bring about a steady increase in the number of electrical appliances owned by private households. This results in an increase in the electricity consumption in EU-27, e.g. from 707.52 TWh up to 806.52 TWh between 1999 and 2006 (Bertoldi and Atanasiu, 2009). On the other hand, energy-efficiency of household appliances has been the focus of many regulations. This resulted in a great progress in the resource-saving design especially of refrigerators, freezers, washing machines, tumble dryers and dishwashers. A report on energy efficiency of household appliances focusing on EU-15 also shows that the electricity consumption of private households can be reduced by changes in consumer behaviour, in addition to improvements in the technical design of appliances (Kemna, 2010).

Behavioural aspects of electricity consumption have already been investigated in several consumer studies. Information is available about washing dishes (Berkholz et al. 2010, Richter 2010), washing laundry (Berkholz et al. 2006, Pakula and Stamminger 2010) and using refrigeration (Thomas 2007, Geppert and Stamminger 2010). The REMODECE Project (de Almeida 2007) provides comprehensive data about energy consumption and consumer behaviour related to large household appliances, but only little information is available about cooking. However, the influence of consumer behaviour on energy consumption is particularly interesting where cooking is concerned. Fechner showed differences of up to 50% in energy consumption when six chefs all cooked the same meal with the same equipment (cited as per Wood and Newborough 2003). This corresponds to the findings of deMerchant (1997) who investigated the influence of inexperienced cooks on energy consumption with cooking systems using electricity. She determined five different cooking styles and reported differences in energy consumption of up to 100%. In her study, a “patient user” used between 485 Wh and 646 Wh for cooking different dishes, and a user following the “hurried style without control” used between 1128 Wh and 1288 Wh for cooking the same dishes (deMerchant, 1997).

The examples show that the energy needed for obtaining the same cooking results differs widely with the chosen method. But more information on the most important cooking processes in private households is needed to be able to give recommendations on how to obtain the requested cooking result with as less electricity as possible.

Methods

In order to obtain reliable results for being able to make a reasonable estimation of the energy-saving potential, the following processes were considered by the authors to be the most relevant and typical cooking processes in European households:

A: Boiling water. Representing hot drinks, soups and parboiling process.

B: Brewing coffee. Representing automated brewing processes.

C: Cooking potatoes. Representing the cooking process itself.

D: Boiling eggs. Representing automated boiling processes.

Different cooking methods are used in households that lead to the same result. Therefore, each process was carried out with various different approaches that are commonly used in households. The prepared amount and, where applicable, the final state being aimed have been varied.

Results

Boiling water

The results for heating up water show that heating in the microwave is possible at practically the same specific energy consumption rates, regardless of the amount of water that has to be heated. However, when using any of the other methods, it makes more sense to heat up larger amounts. For small amounts of water, heating in a pot with and without lid clearly makes less sense, whereas the specific energy consumption for large amounts decreases visibly and falls below the corresponding value for heating in a microwave. As the water is heated at a constant power setting of the hot plate until shortly before the boiling point with only minimum energy loss due to steam development, there is almost no difference in energy consumption when heating water in a pot with and without lid. Heating water in an electric kettle proves to be the most efficient heating method.

Table 1: Specific energy consumption for boiling water

	microwave	ideal pot with lid	electric kettle_1	electric kettle_2	unideal pot without lid
amount of water	Wh/100g				
250	21,1	30,9	14,1	13,8	31,8
500	21,6	22,2	10,9	12,0	22,4
1000	20,7	15,3	9,7	10,4	15,7

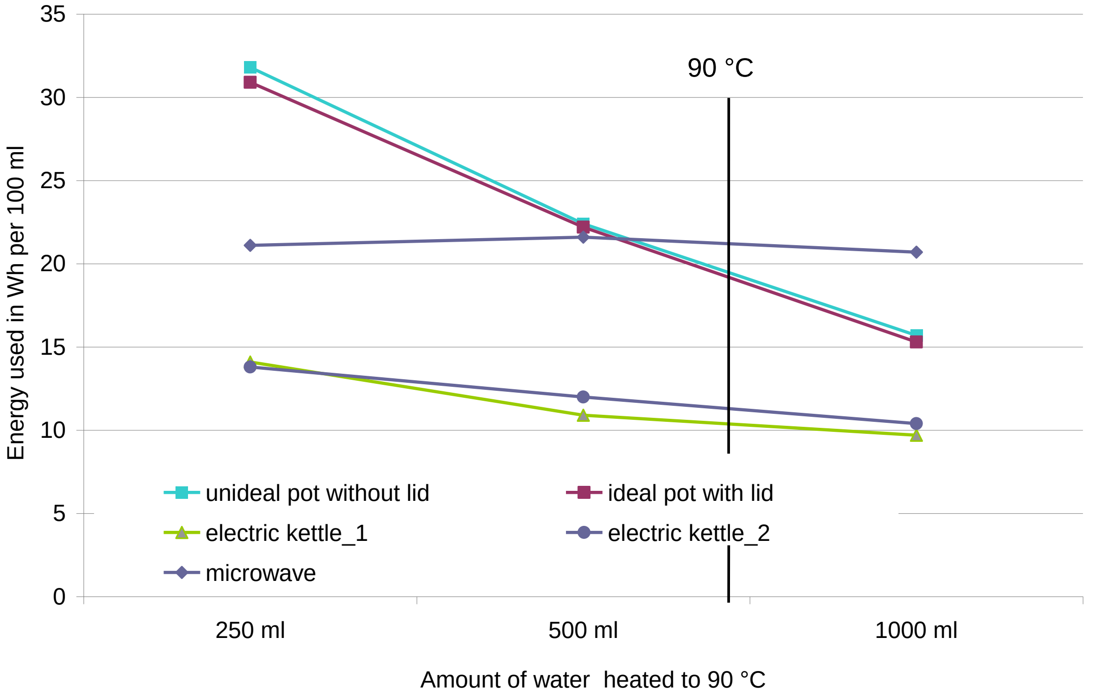


Fig. 1: Specific energy consumption as a function of different amounts of water and different heating appliances. The indicated lines serve as clarification.

Brewing coffee

The energy consumption when brewing coffee by a coffee machine is only about half that required for manual brewing. When using a coffee machine with hot plate, the brewing process needs a similarly low amount of energy as the coffee machine with thermos jug, though extra energy is needed to keep the coffee warm. Keeping the coffee warm can consume significantly more energy than that needed initially to brew the coffee.

Table 2: Energy consumption for brewing coffee

	unit									
number of cups		2			4			8		
amount of water used	ml	300			600			1150		
		amount of coffee brewed								
		coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min
glass jug	ml	262,4	259,7	250,7	538,7	535,1	524,4	1031,2	1026,8	1015,2
thermos jug	ml	244,7	257,8	257,5	531,4	531,2	531,0	1025,0	1026,2	1025,9
brewed manually	ml	251,6	251,5	251,6	522,1	522,1	521,1	979,7	979,6	979,6
		energy consumption for brewing coffee								
		coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min
glass jug	Wh	39,5	64,8	118,3	66,1	87,5	140,6	114,6	137,9	190,0
thermos jug	Wh	37,3	37,3	37,3	63,9	63,9	63,9	110,8	110,8	110,8
brewed manually	Wh	94,5	94,5	94,5	121,9	121,9	121,9	188	188	188
		specific energy consumption for brewing coffee								
		coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min	coffee ready	after 30 min	after 120 min
glass jug	Wh/100 ml	15,1	25,0	47,2	12,3	16,4	26,8	11,1	13,4	18,7
thermos jug	Wh/100 ml	15,2	14,5	14,5	12,0	12,0	12,0	10,8	10,8	10,8
brewed manually	Wh/100 ml	37,6	37,6	37,6	23,3	23,3	23,4	19,2	19,2	19,2

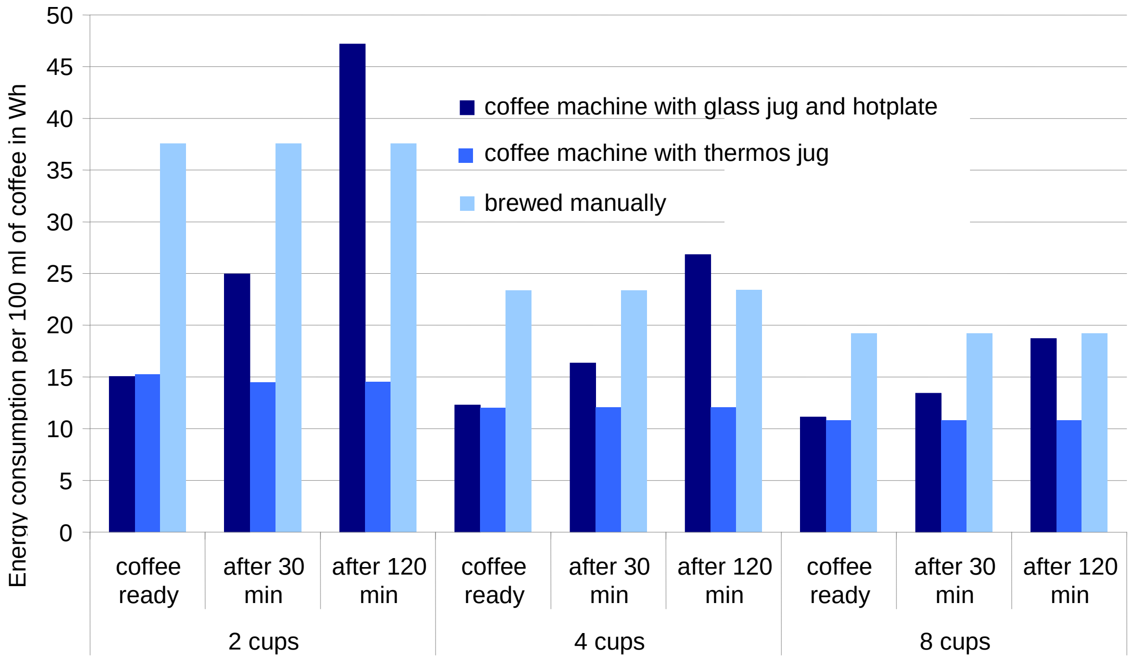


Fig. 2: Average energy consumption per 100 g of brewed coffee.

Cooking potatoes

Total energy consumption for cooking potatoes reveals already significant differences between different cooking procedures, although the end result of the cooking process was always almost identical. The specific energy consumption for cooking 100 g of potatoes as a function of the total amount of cooked potatoes shows in general that it clearly makes more sense in terms of energy consumption to cook larger amounts of potatoes. Regarding the cooking methods, cooking in a pot with lid is the ideal method, providing a better performance than a pressure cooker.

Table 3: Energy consumption for cooking potatoes

amount of potatoes	un-ideal pot without lid	ideal pot with lid	pressure cooker	steam oven
g	Wh	Wh	Wh	Wh
250	509,5	160,5	193,7	336,8
1000	596,7	193,1	256	394,8
2000	658,2	275,4	356,4	471,4
g	Wh/100 g	Wh/100 g	Wh/100 g	Wh/100 g
250	203,8	64,2	77,48	134,72
1000	59,67	19,31	25,6	39,48
2000	32,91	13,77	17,82	23,57

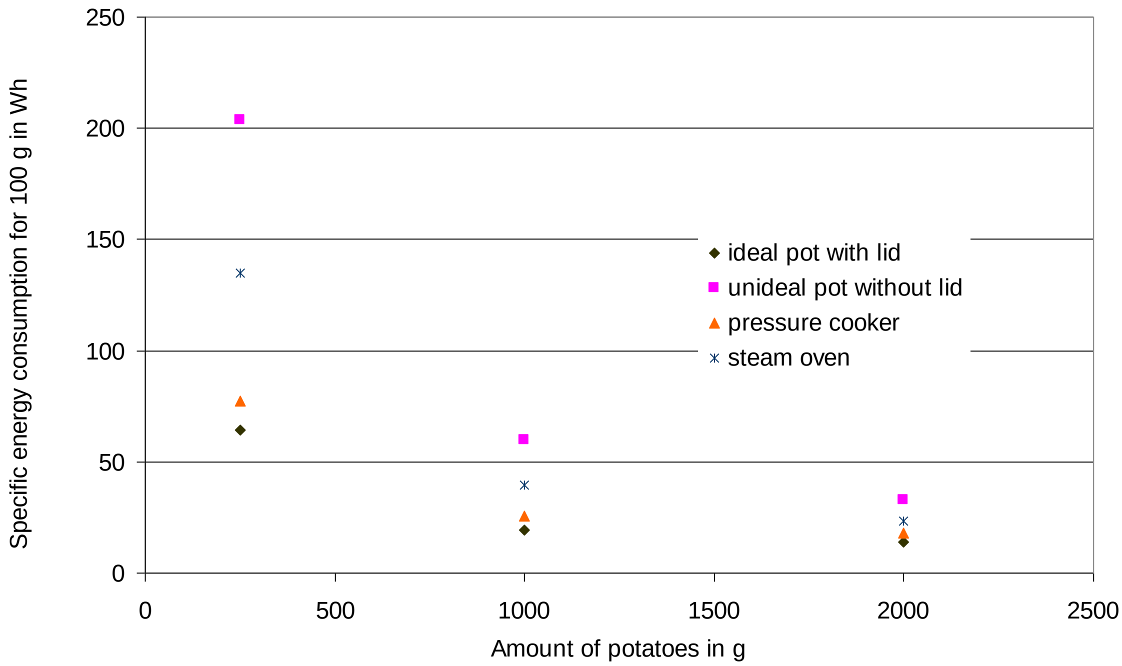


Fig. 3: Medium specific energy consumption per 100 g of potatoes for different cooking methods and for preparing different amounts of cooked potatoes.

Boiling eggs

Energy consumption in this case depends to a large extent on the degree of hardness of the boiled eggs so that energy consumption was determined for different degrees of hardness. As expected, the use of energy increases with rising degree of hardness for all the boiling methods. However, ideal boiling in a pot with lid shows the smallest increase. Depending on the number of boiled eggs, visible differences also become obvious for the specific use of energy.

Table 4: Energy consumption for boiling eggs

degree of hardness	unideal process (pot without lid)	ideal process (pot with lid)	egg cooker_1	egg cooker_2
unit	Wh	Wh	Wh	Wh
2 eggs				
soft	199	112	50	37
medium	258	119	66	60
hard	317	126	82	82
6 eggs				
soft	191	120	60	46
medium	244	126	76	67
hard	296	132	91	88

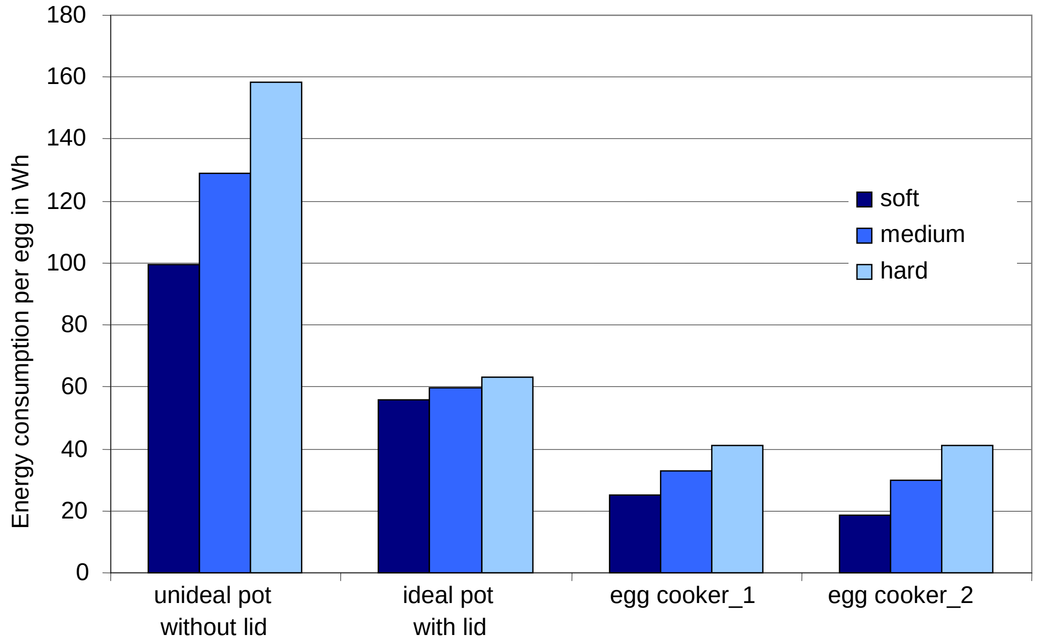


Fig. 4: Energy consumption per egg as a function of the degree of hardness for different cooking appliances when boiling 2 eggs.

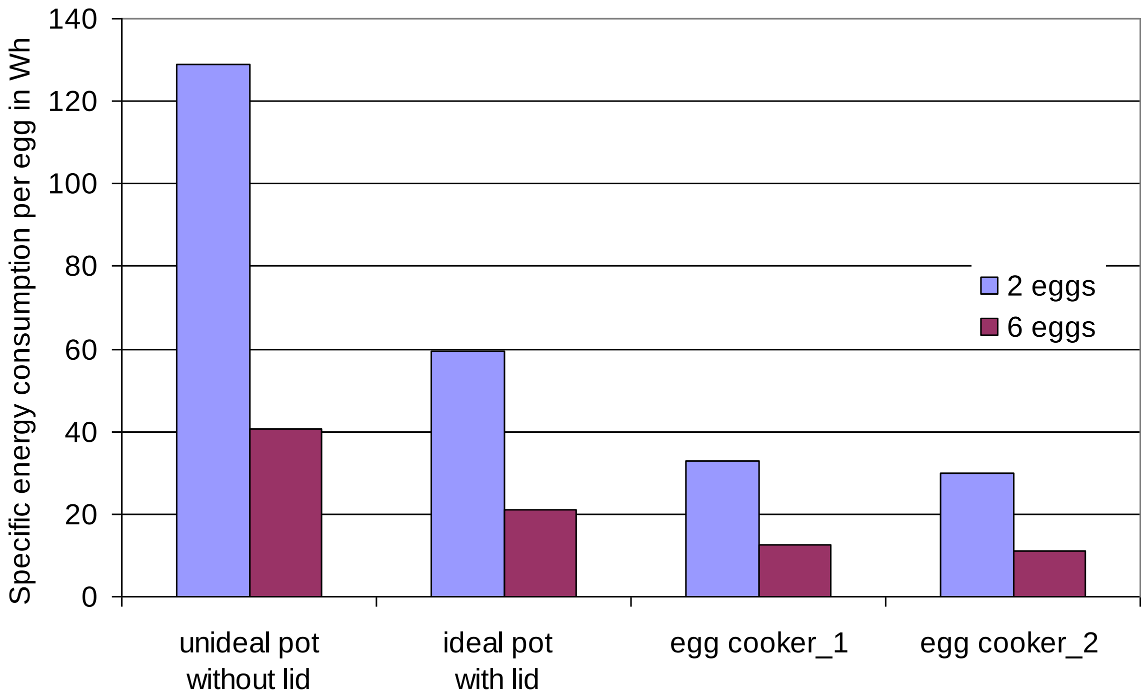


Fig. 5: Specific energy consumption per egg with degree of hardness 'medium' for different cooking appliances, when boiling 2 respectively 6 eggs.

Conclusion and recommendations

The study shows that the energy consumption of typical household cooking processes varies greatly according to the chosen method. In the tests carried out for this study, the method making most sense in terms of energy consumption saved between 50% and 70% energy compared to the least favourable method (table 5). Literature contains reports of between 10% and 77% energy saving potential (table 5). The authors believe that it is possible to save up to 50% in energy consumption for cooking compared to a "non-energy-aware" household when complying with the following recommendations.

Table 5: Estimated energy saving potential of most typical and relevant cooking processes in European households

Recommendation	Estimated energy saving potential	Estimated by
For boiling water, use an electric kettle instead of boiling water in a pot on an electric stove.	- 50%	the authors
For brewing coffee, use a coffee machine instead of brewing coffee manually with water boiled in a pot.	- 50%	the authors
When cooking vegetables, use only small amounts of water, reduce the energy as soon as the water starts boiling and cover the pot with a lid.	- 70%	the authors
Use only small amounts of water (up to 250 ml) when cooking vegetables.	- 30%	Vattenfall, 2008
Use a rice cooker instead of cooking rice in		
- a pot without lid	- 77%	Das et al., 2006
- a pressure cooker	- 42%	Das et al., 2006
Pre-soak rice before cooking it in		
- a microwave	- 10%	Laskhmi et al., 2007
- a pot on an electric stove	- 14%	Das et al., 2006
For boiling eggs use an egg cooker instead of a pot without lid.	- 60%	the authors
Replace an electric oven by a small oven	- 27%	Sidler, 2001

The absolute quantities of energy saved in each described cooking process are not so great, but their significance lies in the fact that they are performed frequently, often on a daily basis or even several times a day. In addition, for most households, these savings can be generated simply by a change in behaviour without an additional investment or only a minimum investment. It can be presumed, for example, that lids are available for the cooking pots. Around 90 % of the households in Europe own an electric kettle, 92 % a coffee machine and 67 % a microwave. The recommendations tend to favour electric appliances especially with an automatic cut-off function. This feature is standard in good quality electric kettles or egg cookers and relieves the user from permanent controlling the cooking process. On the other hand, technical choice and behavioural change mesh, it is therefore hardly possible to separate the influence of the appliance on the energy saving potentials described in table 5. For example, using an electric kettle is the most efficient method for boiling water. But it is possible to make even the electric kettle inefficient, if the user pours too much water into the kettle.

The recommendations in table 5 are easy to carry out. Almost everybody is affected in one way or the other. It is therefore highly desirable to promote and achieve energy-conscious behaviour in cooking courses for adults and children, at the point of sale, on the internet, in cookbooks, magazines and other publications, to name but a few promising possibilities.

References

The detailed description of material, methods, results, conclusions as well as the recommendations is given in the article:

Oberascher C., Pakula C. and Stamminger R. *Energy efficiency in daily food preparation*. International Journal of Consumer Studies, Special Issue on Household Technology and Sustainability. March 2011.

Ecodesign of domestic ovens, hobs and grills

Shailendra Mudgal*, Benoît Tinetti*, Eric Hoa*, Guillaume Audard*, Paul Goodman**, Chris Robertson**

****BIO Intelligence Service, **ERA Technology Ltd.***

Abstract

This paper highlights the key findings of the Ecodesign preparatory studies on domestic ovens (lot 22), hobs and grills (lot 23), which are contracted by DG ENER. They provide the basis for considering implementing measures with regard to potential energy savings and the EU 2020 strategy. The analysis is based on the MEEuP methodology taking into account a life cycle perspective and following a logical series of steps: scope definition, market analysis, user behaviour aspects, systems analysis, environmental assessment of the current products, and improvement potential through product design. Life cycle costs (LCC) induced by the improvement options are further considered. The point of least life cycle costs (LLCC) for the consumer could be identified as a short-term target, whereas "best available technology" (BAT) option may stand as a relevant target for a long-term perspective. The analysis takes into account all major technical parameters relevant for cooking appliances but also considers the role of end-users in improving the environmental performance of the products.

The study builds on five average EU products ("Base-cases") covering different product functionalities and energy sources: gas/electric ovens, microwave oven and gas/electric hobs. The diversity of domestic grills and their relatively low frequency of use did not enable to set up a distinct average Base-case for grills. The chosen Base-cases serve as reference points for the assessment of the environmental impacts and potential improvement options of the current cooking appliances on the EU market. Final results highlight the predominant impact of the use phase. The effects of various improvement options (and their combinations), which consider a reduced energy requirement along the life-cycle as well as the additional cost for their implementations, are further investigated and potential implementing measures – including energy labelling – are approached.

Introduction

Legislative background

The Ecodesign Directive is a framework Directive on ecodesign requirements (2009/125/EC). Since 2005, analyses of different product groups are under process to develop detailed ecodesign requirements for specific products. These requirements are developed in a multi-step process:

1. **Preparatory Studies,** by independent consultants, analyse a specific product category regarding environmental performance throughout the full product life cycle and regarding improvement potentials, i.e. technology options with significantly lower environmental impact at any life cycle step.

2. On the basis of preparatory study, the European Commission outlines possible product ecodesign requirements in a **Working Document**, which are presented and discussed at a **Consultation Forum** meeting with stakeholders.

3. Based on these discussions and further evidence, the European Commission drafts an **Implementing Measure** for vote by the **Regulatory Committee**.

4. After an inter-service consultation at the Commission, a scrutiny by the European Parliament, and a **notification to the WTO**, the adapted **Implementing Measure / Commission Regulation** is be adopted and published in the **Official Journal of the European Union**.
5. The requirements laid down in the Implementing Measure are **directly effective** in all the Member States from the date of its publication itself.

Preparatory Studies on domestic ovens, hobs and grills.

Among the residential appliances covered by the Working Plan for 2009-2011 under the EU Ecodesign Directive (2009/125/EC), cooking appliances are the most energy consuming ones (7% of the electricity consumption among residential equipment in the EU-15 in 2004 [1]).

This paper presents the main results of the preparatory studies on domestic ovens, hobs and grills that were finalised in April 2011. They include technical, economical, and environmental impact assessments which will provide the technical basis to draft any possible implementing measures (legislation) for setting generic and specific ecodesign requirements on cooking appliances. The studies follow the Methodology for Ecodesign of Energy-using-Products (MEEuP) [2] which is a common approach for all preparatory studies. It includes a definition of the product categories (Task 1), market analysis (Task 2), aspects of user behaviour and related barriers for ecodesign (Task 3), analysis of real products being identified as representative of the European situation (Task 4), environmental assessment of average products defined as Base-Cases, system analysis (Task 5), in depth technical analysis of best available (and not yet available) technologies, possible improvement potential of different design options (Tasks 6 and 7), and policy and scenario analysis (Task 8). The MEEuP also involves a spreadsheet model (EcoReport) using an internal database that converts material quantities from Bill-of-Material (BOM), energy consumption data and economic data into quantified impacts on standard environmental indicators and Life Cycle Cost (LCC).

Product scope and existing legislations and testing procedures

Product scope

In the study, an oven is defined as “an enclosed compartment where the power/temperature can be adjusted for heating, baking and drying food” and it is thereby used for cooking. It means that ovens used for applications other than food will not be considered. Domestic ovens represent a wide and fragmented product group, with many options in terms of energy sources (e.g. gas, electric or mixed), sizes, configurations (i.e. free-standing or built-in) and operational modes (e.g. fan forced, conventional, microwave, grill, steam or combined modes).

Likewise, a hob is defined as “an appliance or part of an appliance which incorporates one or several distinguishable cooking zones, where pans can be placed on for heating”, and a grill as “an appliance or part of an appliance in which food is cooked by radiant or contact heat”. Such appliances may differ by their energy sources (e.g. gas, electric or mixed), sizes (e.g. number of cooking zones), configurations (i.e. free-standing or built-in), heating mechanisms (e.g. conduction, convection or electromagnetic field for hobs, radiation or conduction for grills) and technologies (e.g. solid plate, radiant resistance, induction for electric hobs)

Ovens and hobs that are incorporated within domestic cookers are part of the study scope whereas commercial (yet within the lots 22/23 scope) and industrial cooking appliances are not discussed in this paper.

Existing standards and legislation at EU Level

Product standards establish requirements related to the design, manufacturing, construction, performance (energy efficiency and emissions of pollutants) and safety use instructions. Currently, most European standards that concern cooking appliances address safety issues, but there is the EN 50304/60350:2009 standard based on a “chilled wet brick” test, which covers energy efficiency for domestic electric ovens, under the EU Energy Labelling Directive 2002/40/EC. The resulting energy label shows energy class A to G and energy consumption in kilowatt hours (kWh) per cycle depending on the heating mode and the cavity volume. That helps consumers to compare appliances but also drive improvements in product performance through market competition. Currently, there is no mandatory EU label for other household cooking appliances.

Furthermore, a horizontal measure on standby power consumption adopted under the Ecodesign Directive includes domestic electric cooking appliances and notably requires a maximum consumption of 1W in stand-by and off modes (Regulation No.1275/2008).

Market Analysis at EU level

The information for the market analysis of domestic cooking appliances at EU level is mainly based on 2007 market figures bought from GfK Retail and Technology GmbH, which include sales quantification and adjustment considering a "Total Market coverage ratio", when Member State information were missing.

Market sales and related forecasts

The numbers of domestic ovens (including cookers) and microwave ovens sold in the EU market on 2007 are presented in Figure 1 according to their configurations (built-in or free-standing) and energy sources.

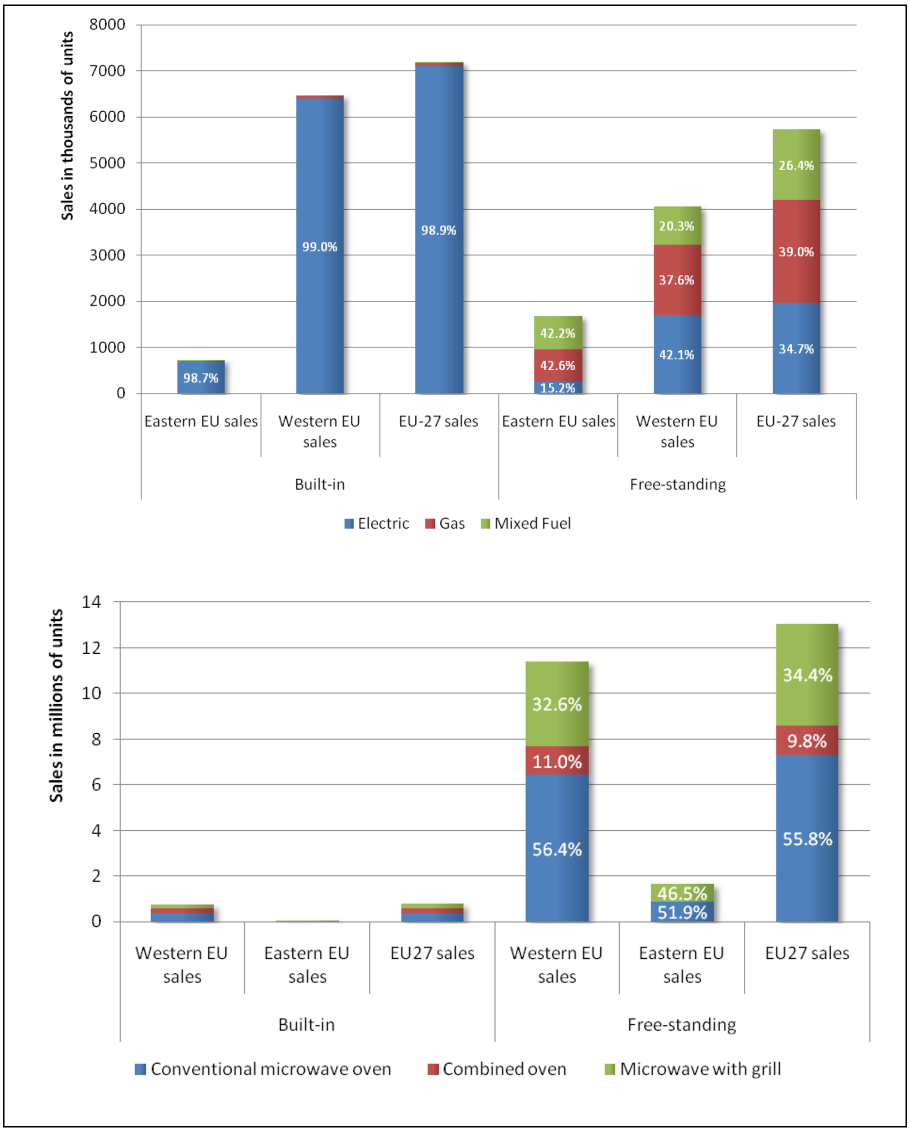


Figure 1: Estimated sales of domestic ovens (including cookers) (top) and microwave ovens (bottom) in the EU in 2007 per type of appliance and energy source [3]

Most of the built-in ovens sold in 2007 were powered by electricity. There was no significant difference between the Eastern EU and Western EU markets except for the volume of sales that is higher in Western Member states. Regarding microwave ovens, conventional microwave ovens are the appliance most sold in the EU-27.

Regarding domestic hobs, Figure 2 gives an overview of around 8.7 million hobs that were sold in 2007 in the EU, the majority (59.6%) being electric hobs. Among the latter, the preferred technology was radiant hobs (including halogen or not) with 70.8% of the sales.

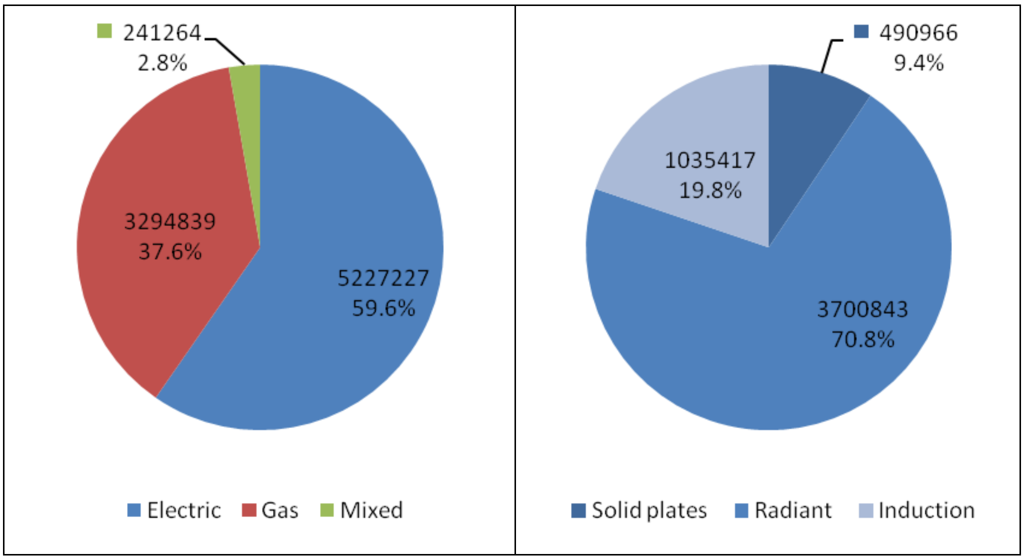


Figure 2: Estimated sales in units and percentages of domestic hobs in EU-27 in 2007 (left), and distribution of technologies for the domestic electric hobs (right) [2]

Based on feedback from stakeholders, the following assumptions were made to estimate the evolution of the sales until 2025:

- The overall sales of domestic ovens and hobs will carry on growing until 2025. In 2025, the sales will be 4.5 to 5.5% higher than in 2007. This range is rather consistent with the estimated evolution of the number of households in the EU [4].
- Sales of microwave ovens will carry on growing in the EU-27 but the annual growth rate will decrease from 2010 to 2025 as the market is reaching saturation.
- Sales of built-in appliances (for ovens and cookers) will increase, while free-standing appliances will be less and less sold.
- The total cookers sales (both built-in and free-standing) will decrease in favour of built-in electric ovens.
- Sales of electric appliances will increase while sales of gas and mixed appliances will decrease or remain constant.
- Within the electric hobs, the number of induction systems will significantly increase whereas solid plates will be less and less sold.

The resulting forecast is presented in Figure 3

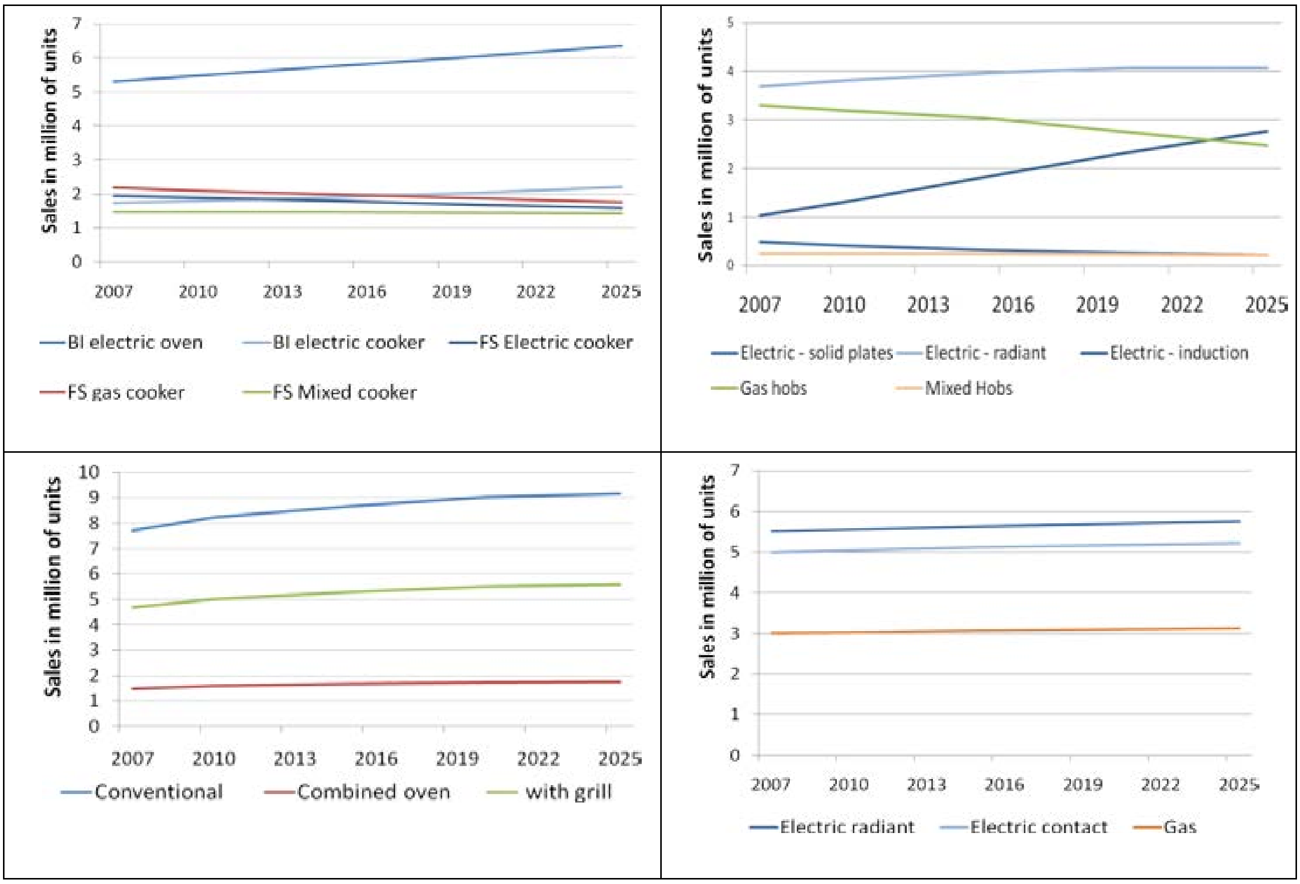


Figure 3: Estimated forecasts for sales of domestic cooking appliances in EU from 2007 until 2025– ovens (including cookers) (top-left), microwave ovens (bottom-left), hobs (top-right), grills (bottom-right). (BI: built-in / FS: free-standing)

Market stock and related forecasts

No published figures are available concerning the overall stock of domestic cooking appliances at EU level. A first approach to estimate this stock is to multiply the annual sales by the average lifetime of the appliances, which was estimated to 19 years for all domestic cooking appliances, except for induction hobs (15 years). However, with this approach, the sales would be considered to have been constant for the past 19 years, which is rather unrealistic. Therefore, adjustments to these results and related forecasts were made with respect to the recent trends and complementary feedbacks from stakeholders and are presented in Table 1.

Table 1: Estimated forecasts for stocks of domestic cooking appliances in EU from 2007 until 2025. (BI: built-in / FS: free-standing)

	2007	2010	2015	2020	2025
BI electric oven	95,000,000	97,878,595	103,893,957	110,279,008	115,904,346
BI electric cooker	15,000,000	15,454,515	16,648,902	17,935,596	18,850,491
FS Electric cooker	35,000,000	33,960,465	31,488,704	29,196,846	27,765,910
FS gas cooker	50,000,000	49,253,744	48,034,652	45,680,476	43,441,678
FS Mixed cooker	20,000,000	20,301,503	21,337,083	20,808,964	20,808,964
Conventional microwave oven	69,297,094	71,821,845	73,635,437	74,746,616	75,497,078
Combined microwave oven	13,373,874	13,861,135	14,211,146	14,425,596	14,570,430

	2007	2010	2015	2020	2025
Microwave oven with grill	42,172,878	43,709,393	44,813,110	45,489,352	45,946,069
Gas hobs	62,150,000	60,441,521	57,486,636	54,676,571	52,004,226
Electric hobs - Solid plates	12,000,000	10,952,076	9,404,920	8,720,397	8,085,696
Electric hobs - Radiant	55,000,000	56,666,555	58,969,775	60,458,836	60,458,836
Electric hobs - Induction	4,500,000	6,322,176	11,141,834	17,944,036	26,365,675
Mixed hobs	4,200,000	4,200,000	4200000	4105450	4,013,241
Gas grills (radiant)	57,000,000	57,514,541	58,382,451	58,968,615	59,560,665
Electric radiant grills	104,500,000	105,443,324	107,034,493	108,109,127	109,194,552
Electric contact grills	95,000,000	95,857,568	97,304,084	98,281,025	99,267,774

Consumer Behaviour: Use pattern

Like all domestic energy-using products, cooking appliances' energy consumptions depend on both the power requirements and on the use pattern (i.e. frequency of use, duration, type of meals, temperature). Such factors can account for an overall energy consumption variation of up to 30% within the same type of appliance. Based on different sources of information at EU and Member State levels and feedback from stakeholders, average typical scenarios were defined for the study. They are characterized in Table 2 for (microwave) ovens and Table 3 for hobs and grills

Table 2: Use pattern for domestic ovens

		Unit	Electric ovens	Gas ovens	Microwave ovens
On-mode	Number of cycles per year (on-mode)		110	110	1200
	Average duration of a cycle	Min/cycle	55'	55'	2'36''
	Final Energy consumption per cycle	kWh/cycle	1.1	1.67	0.056
Stand-by mode	Number of hours		8595	-	8708
	Electricity consumption per hour	kWh/h	0.005	-	0.0022
Annual energy consumption		kWh/year	164	184	86

Table 3: Use pattern for domestic hobs and grills

	Unit	Gas hobs	Electric hobs - Solid plates	Electric hobs - Radiant	Electric hobs - Induction	Gas grills (radiant)	Electric grills - radiant	Electric grills - contact
Number of uses per year		438	438	438	438	52	52	52
Final Energy consumption per use - in average	kWh/use	0.75	0.57	0.55	0.43	0.96	0.96	0.96
Annual energy consumption	kWh/year	330	250	240	190	50	50	50

Product Assessments

Technical analysis existing products

In order to evaluate the life cycle impacts of domestic cooking appliances, a technical analysis of existing products was performed, with a focus on the collection of Bill-of-Materials (BOM) to be used as inputs to define the Base-cases. Figure 4 presents some technical characterization of an electric oven and a gas hob.

The construction of most modern mass-produced domestic ovens is relatively simple. They are generally constructed from pressed steel to form a cavity that is wrapped in thermal insulation with a hinged and usually glazed door at the front (for easy access to insert and remove food), and a vent or flue. To maintain external surface temperatures as low as possible the door is usually double glazed with an infrared reflective coating applied to the inner pane. There are three main methods of heating: gas, electric resistance or microwave. In operation the oven temperature is regulated by thermostatic control of the gas burner or electricity supply or in the case of a microwave oven control of the magnetron. For electric and gas heating ovens, less than 20% of the energy is transferred to the food as a large proportion of the energy input to an oven is lost through the walls, door, vent or flue. The figure for microwave ovens is however higher (around 40-50%).

Hobs use four major types of heating: gas burners and three basic electric types: coil element or solid plate (resistance heating), radiant (e.g. halogen) and induction. Apart from induction, the hob is the primary heat source which is used to heat the cooking vessel which then becomes the secondary heating source, transferring heat to the food within it. Induction heating makes the cooking vessel the primary heating source by generating electrical eddy currents within the ferromagnetic material used for the cooking vessel. The energy efficiency of a hob is affected by many variables including the distance between the base of the pan and the burner (for gas hobs) or the pot design (i.e. flat bottom) for electric hotplates.

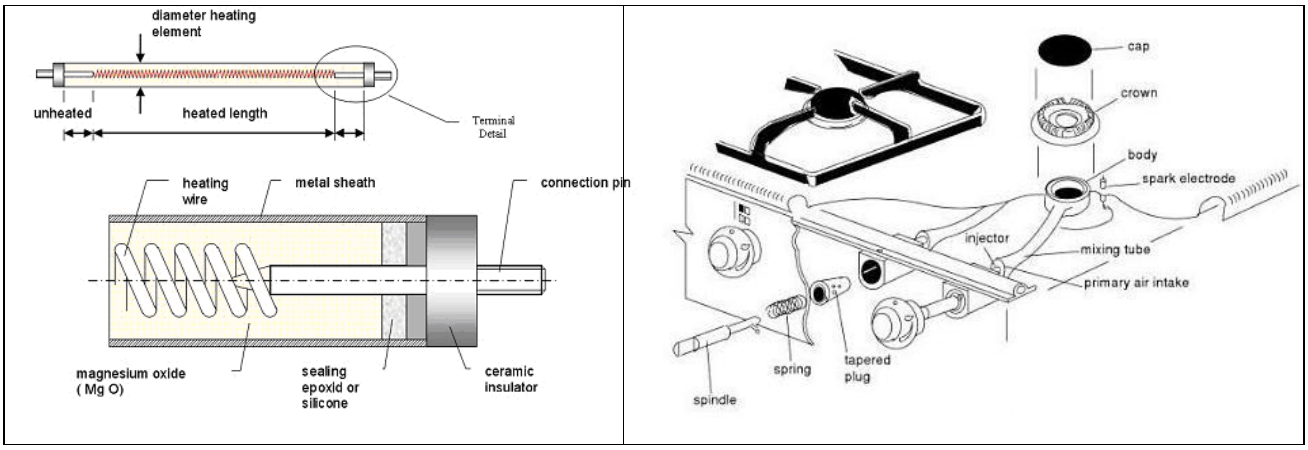


Figure 4: Schematic diagram showing the electric heating element in an electric oven (left) [5] and the basic design of a gas hob (right) [6]

There are many different designs of domestic grills on the EU market. These can be split into two main types: (i) Radiant – where the food is not in contact with the heat source and (ii) contact grills – where the food is placed onto the heated grill or griddle surface.

Definition of the Base-cases

In order to cover appropriately the broad range of technical specifications and functionalities of domestic cooking appliances, five Base-cases (representative of current products) were defined as summarised in Table 4. Given the design diversity of domestic grills and their relatively low frequency of use, no distinct average Base-case for domestic grills was further investigated.

Table 4: Definition of domestic Base-cases

Base-case	Configuration	Capacity (L) or number of cooking zones	Total power (W)	Average Price (€)
BC1 - Domestic electric oven	Built-in independent	54 L	3,570	500
BC2 - Domestic gas oven	Free-standing dependant (used in cooker)	58 L	10,500 (within a cooker)	330
BC3 - Domestic microwave oven	Free-standing independent	18 L	1,150	117
BC4 - Domestic electric (radiant) hob	Built-in independent	4 cooking zones	7,400	380
BC5 - Domestic gas hob	Built-in independent	4 cooking zones	9,000	268

Environmental Assessment of the Base-Cases

The Base-cases serve as reference points for the assessment of the environmental impacts of current products on the EU market and calculation of the associated Life Cycle Costs (LCC). The life cycle environmental impacts were evaluated through the EcoReport spreadsheet model based on the inputs presented in Tables 1 to 4, considering a representative product life of 19 years. A typical end-of-life scenario for domestic cooking appliances was also estimated, based on literature review and stakeholders' feedbacks.

Results of the life cycle environmental assessment of the Base-case on domestic electric oven is presented in Table 5 and in Figure 5.

Table 5: EcoReport outcomes

Life Cycle phases -->		**PRODUCTION**			**DISTRI-BUTION**	**USE**	**END-OF-LIFE***			**TOTAL**
Resources Use and Emissions		Material	Manuf.	**Total**			Disposal	Recycl.	**Total**	
Total Energy (GER)	MJ	970	250	**1220**	**448**	**32826**	48	35	**12**	**34506**
of which, electricity (in primary MJ)		MJ	229	149	**378**	**1**	**32782**	0	3	**-3 33158**
Water (process)	ltr	246	2	**248**	**0**	**2188**	0	2	**-2**	**2434**
Water (cooling)	ltr	179	69	**248**	**0**	**87410**	0	15	**-15**	**87643**
Waste, non-haz./ landfill	g	36475	884	**37359**	**242**	**38378**	759	10	**749**	**76728**
Waste, hazardous/ incinerated	g	88	0	**88**	**5**	**756**	14	2	**12**	**862**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.		73	14	**87**	**28**	**1434**	4	1	**3 1551**
Ozone Depletion, emissions	mg R-11 eq. negligible									
Acidification, emissions	g SO2 eq.	350	60	**410**	**84**	**8447**	8	2	**6**	**8947**
Volatile Organic Compounds (VOC)		g	4	0	**4**	**6**	**13**	0	0	**0 23**
Persistent Organic Pollutants (POP)		ng i-Teq	473	8	**481**	**1**	**220**	5	0	**5 707**
Heavy Metals	mg Ni eq.	278	18	**296**	**12**	**573**	14	0	**14**	**895**
PAHs	mg Ni eq.	19	0	**19**	**16**	**73**	0	0	**0**	**107**
Particulate Matter (PM, dust)	g	64	9	**73**	**999**	**313**	77	0	**76**	**1461**
Emissions (Water)										
Heavy Metals	mg Hg/20	238	0	**238**	**0**	**214**	4	0	**4**	**456**
Eutrophication	g PO4	7	0	**7**	**0**	**1**	0	0	**0**	**8**
Persistent Organic Pollutants (POP)	negligible	ng i-Teq								

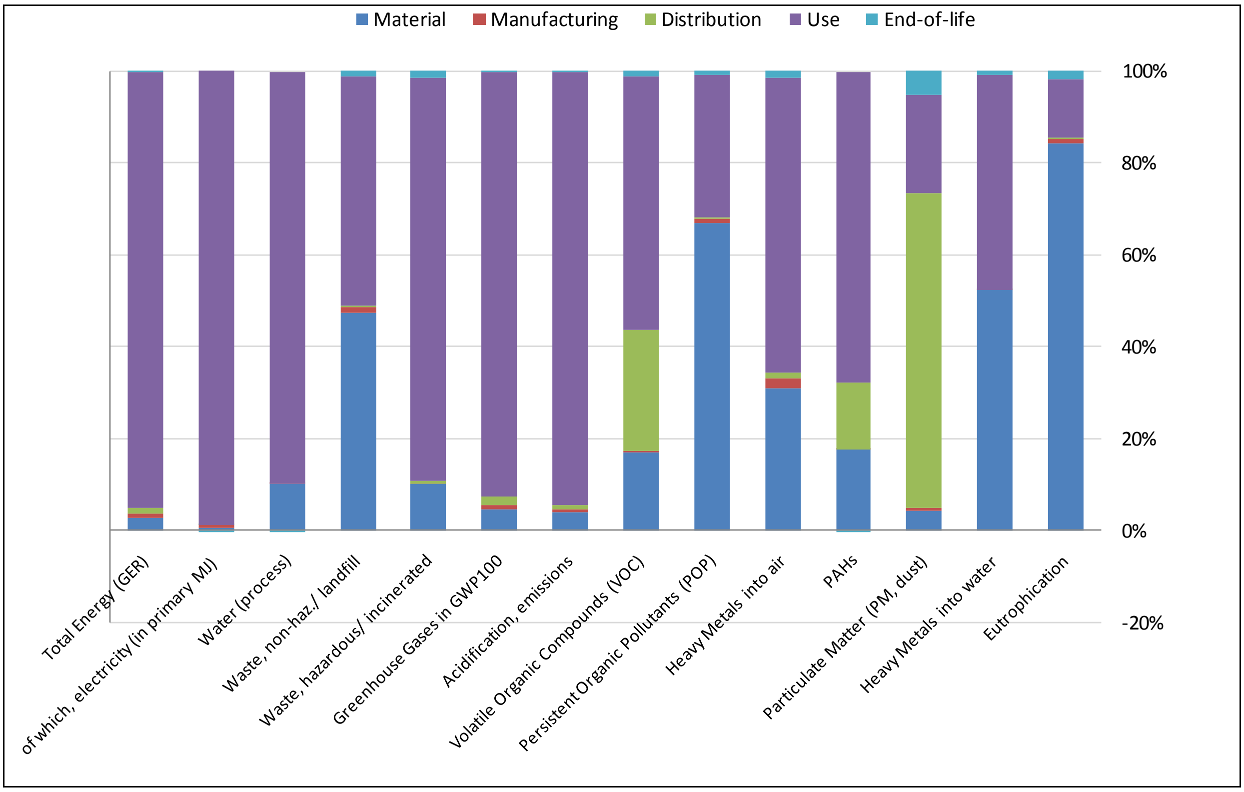


Figure 5: Distribution of environmental impacts for the domestic electric oven, per life cycle phase

For BC1 on the domestic electric oven, the analysis shows that:

1. The use phase impacts are dominating the total environmental impacts for most indicators: Total Energy (GER), Water (process), Waste (hazardous / incinerated), Greenhouse gases, Acidification (emissions to air), Volatile Organic Compounds, Heavy metals emissions to the air and PAHs (emissions to the air).

2. Material acquisition is predominant in the total environmental impact for several indicators: Waste (non-hazardous / landfill), Persistent Organic Pollutants (POP), Heavy metals emissions to water and Eutrophication (mainly due to the galvanized steel used for the casing).

3. Manufacturing and end-of-life is not impacting any of the categories.

4. Distribution is dominating in the case of Particulate matter emissions to the air.

For the other Base-cases, the trends are similar - with the clear identification of the use phase as the most impacting phase - even if the quantitative values differ. In that regard, Table 6 presents the energy consumptions related to the 5 base-cases, at product and EU levels.

Table 6: Energy consumptions of domestic cooking appliances

Base-Case	Total Energy per unit (GJ) over product lifetime	Total Energy of the EU stock (PJ) in 2007
BC1 - Domestic electric oven	34.5	266
BC2 - Domestic gas oven	15.9	41
BC3 - Domestic microwave oven	8.9	136

Base-Case	Total Energy per unit (GJ) over product lifetime	Total Energy of the EU stock (PJ) in 2007
BC4 - Domestic electric (radiant) hob	49.4	188
BC5 - Domestic gas hob	24.4	80

Analysis of the Improvement Potential

A thorough description and technical assessment of Best Available Technologies (BAT) and Best Not yet Available Technologies (BNAT), either at product or component level, and an analysis of best available products on the market allowed identifying relevant technical options which could be feasible and available (short and long term) to improve the environmental performance of domestic cooking appliances..

Thirteen different improvement options were identified as relevant for at least one Base-Case: (1) enhanced door glazing; (2) introduction of a reflecting layer; (3) better insulation; (4) enhanced temperature and heat accuracy by electronic control; (5*) cooking sensors; (6) reduced thermal mass; (7) pre-heating ventilation air with heat exchanger; (8) painted cavity; (9) inverter power supply (10) better engineering work; (11) cavity light (with LEDs); (12*) pot sensors and (13) individually controlled multiple crown burners. The implementation of the standby Regulation (1275/2008/EC) is considered as option (0). Moreover, pot and cooking sensors are user-dependent options - marked with (*) - and therefore, the related energy savings are more subjective and may not be directly measured within a test standard.

Consequently, the improved Base-cases (i.e. by implementing one improvement option on the top of a Base-Case) were analysed again using the EcoReport tool with modified bills-of-materials, energy consumption and additional costs. Results were compared with the standard Base-Case and suggest that options 1, 3 and 6 seem to be cost-efficient options with payback times ranging from 4 to 17 years – which are below the 19 year-product lifetime. Scenarios (i.e. combinations) of compatible improvement options were also modelled in order to enhance greater potential. As it can be seen in Figure 6, this approach enabled to identify the point of least life cycle cost (LLCC) for the consumer and the BAT option/scenario which leads to the best environmental performance in terms of energy consumption and might therefore serve as a target in the long-term.

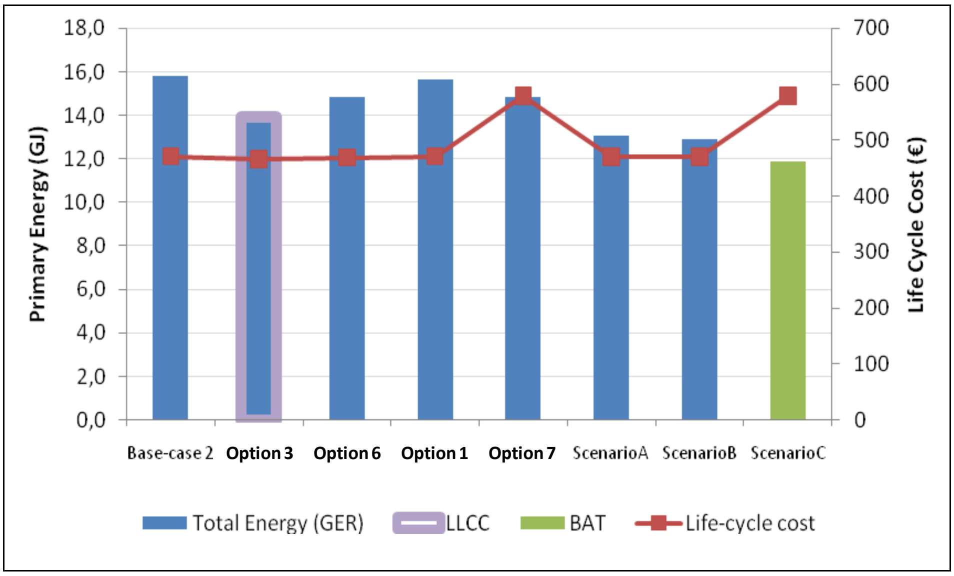


Figure 6: Identification of BAT and LLCC for domestic gas oven (Scenario A = combined options 3 and 6; Scenario B = combined options 3, 6 and 1; Scenario C = combined options 3, 6, 1 and 7)

The overall analysis shows that scenarios leading to LLCC points allow the reduction of total energy requirements (TER) from 0 to 39%. This upper value refers to the domestic electric oven and actually translates the recent improvement induced by the existence of an energy label for these appliances. The scenarios leading to BAT points achieve TER reductions between 2%-41% considering user-independent options and between 14%-42% considering the use of sensors. In the latter case, a significant increase in LCC (up to 46%) is observed. Table 7 summarises the LCC and TER impacts (in comparison with the values obtained for the Base-case) for the LLCC and BAT options.

Table 7: Overview of the relevant options for the Base-case (in black), LLCC (in orange) and BAT (in green) scenarios. Figures in brackets refer to user-dependent scenarios where sensors (*) are used.

Base-case LLCC BAT	Improvement options														Total Energy	LLC
	0	1	2	3	4	5*	6	7	8	9	10	11	12*	13		
BC1	x	x	x	x	x	x										
	x	x		x											-39%	-16%
	x	x	x	x	x	(x)									-41% (-42%)	-4.3% (-2.5%)
BC2		x		x			x	x								
		x													-12%	-1%
		x		x			x	x							-25%	+23%
BC3	x					x			x	x	x	x				
	x														-10%	-5%
	x					(x)			x	x	x	x			-15% (-16%)	+0.5% (+46%)
BC4					x	x							x			
	Identical as base-case														0%	0%
					x	(x)							(x)		-2% (-14%)	+4% (+8%)
BC5					x	x							x	x		
	Identical as base-case														0%	0%
					x	(x)							(x)	x	-5% (-16%)	+24% (+39%)

Scenario analysis and implementing measures

A scenario analysis is performed by modelling the implementation of LLCC, BAT (with or without sensors) as minimum energy performance standards (MEPS) in the short-term (2015). In practice, such measures clearly depend on the establishment of harmonised test standards which would enable an objective evaluation of the cooking appliances and a further calibration of the tentative MEPS. Current standardisation work led by CENELEC and CEN committees for domestic cooking appliances is therefore decisive in that regard. Table 8 presents the quantitative energy savings based on these scenarios.

Table 8: Savings for the domestic sector, cumulative 2010-2025, compared to BAU

Savings over the period 2010-2025 (PJ)	**LLCC**	**BAT** (with / without sensors)
Domestic ovens	43.5	93
Domestic hobs	0	193 / 38
Total	43.5	286 / 131

Such standardisation would also enable the potential implementation of an energy labelling scheme. For cooking appliances, the question whether a common approach for gas and electric appliances should be taken (given the existence of a common standard) or a separate one is raised. A common label would then be based on primary energy considerations, which directly relates to the environmental impacts whereas a separate approach would allow final energy consumptions to be expressed in billing units, which would make the classification easier to understand for consumers. Such issue will need to be first addressed for the domestic ovens as a label for electric ovens already exists. Revised and potential new labelling schemes should ensure consistency within the cooking appliances.

Conclusions

The most energy-demanding phase for domestic cooking appliances is the use phase. The study shows that the potential energy savings range between 2% (for the domestic electric hob) and 41% (which have already been implemented for the domestic electric oven, thanks to the current energy label) when cumulating several improvement options. Hence, a potential integration into the product design seems beneficial.

However, any improvement action to reduce the related energy consumption also implies the addition of complementary components such as cooking and pot sensors, which cause a significant increase in the life cycle cost of the product. Still, it should be kept in mind that such results are based on various assumptions including the price and energy consumption of the base-cases, the choice and estimated size of improvement options, and the energy tariff. The prices of options are estimated by manufacturers and may represent initial market entry prices for high-end models with few sales whereas if these options are widely adopted for hobs, economies of scale and competition are likely to reduce these to some extent. Besides, significant energy savings can additionally be achieved by influencing how the cooking appliances are used by the consumer.

Mandatory and/or voluntary measures (e.g. industry agreement) could help in achieving these improvement targets.

References

[1] Bertoldi, P. and Atanasiu, B. (2006), *"Electricity Consumption and Efficiency Trends in the Enlarged European Union", Status report.*

[2] VHK (2005) *Methodology Study Eco-design of Energy-using Products Final Report. Prepared for the European Commission DG ENTR*.

[3] GfK Retail and Technology GmbH (2007), *Market data for domestic ovens and hobs.*

[4] Eurostat (2007), www.eurostat.com

[5] Elmatic [Cardiff] Ltd

[6] Gas Installation Technology by R D Treloar (2005). *With thanks for permission to include this diagram Wiley-Blackwell Publishing Ltd.*

Solutions for Zero Standby and No Load Consumption

Mike Matthews

Director of Strategic Marketing - Power Integrations

Abstract

System and IC solutions to reduce standby and no load consumption have made great strides in recent years, however, the availability of a simple and cost effective means to achieve zero consumption has remained elusive. Some ‘zero’ consumption solutions have been proposed and implemented but have to date required bulky and or costly configurations using relays, manual switches and in some cases even back up batteries within phone chargers to give the illusion of zero no load consumption

Even the definition of ‘zero’ is a topic of debate depending on the equipment. Some companies have proposed standby consumption in a domestic appliance or TV of below 50mW allowing a claim of 0.0W consumption. The most stringent no-load targets in mobile phone chargers are already <5mW @ 230Vac input or in other words, 0.00W of consumption.

Seeking ever lower consumption only makes sense if the solution does not cost more than the energy savings provided. It is to this end that Power Integrations has released a series of cost effective products which meet the most stringent IEC62301 ‘zero’ consumption definition of <5mW when connected to a 230VAC supply.

This paper discusses the potential application of these products in a variety of consumer applications such as phone chargers, TVs and major appliances.

Introduction

Standby power consumption as a percentage of domestic electricity usage can be as high as 10% [1], and in the UK alone it has been estimated that enough standby power is consumed to power 400,000 homes [2]. In recent years there have been significant efforts to reduce standby energy consumption and to raise awareness amongst consumers. However one of the communication challenges is to maintain a clear message for a largely non-technical consumer audience. So despite mobile phone chargers in some cases now having no-load consumption below 30mW, it is difficult to market this as a benefit over previous claims of 150mW or 500mW performance which, to the non-technical ear, are somewhat abstract.

With respect to message clarity for consumers, absolute statements work well. What could be clearer than simply ‘zero consumption’?

Of course zero consumption has always been possible simply by disconnecting a phone charger or appliance from the AC supply when not in use. However the inconvenience of doing this has meant that it is not a realistic solution to the growing problem of standby consumption. There has therefore been much activity in recent years to develop technical solutions that can achieve zero consumption while retaining functionality and convenience for the consumer. Certain solutions have been proposed for mobile phone chargers but have either still required user intervention to achieve zero power or in some cases even employ internal battery backup cells to create the illusion of zero consumption when the load is disconnected [3].

In arriving at a solution that achieves zero consumption without these shortcomings, it is first important to establish the target

What is Zero?

Since there is always some leakage current present even with mechanical switches, it is necessary to define the threshold below which ‘zero’ can be claimed. Fortunately there is a globally recognized standard IEC 62301 that makes this definition [4]. The relevant section 4.5 states that for power measurements of 10Watts or less, a measurement resolution of 0.01W (10mW) must be used.

Therefore any measurement of <5mW is rounded to zero. There is of course another way to state this same fact by quoting energy consumption to the second decimal place. Therefore a power consumption of <5mW can also be stated as 0.00W consumption.

Although <5mW makes sense as the definition of ‘zero’ for small power supplies such as mobile phone chargers, larger systems such as white goods domestic appliances may apply different standards by using fewer decimal places - for example 0.0W standby covers consumption <50mW.

The following sections discuss a few typical applications along with the operating principles of a family of integrated circuits providing solutions for zero no load and zero standby consumption in a variety of consumer applications. The LinkZero, CAPZero and SENZero ICs provide developers solutions for zero consumption where no behavior changes are required of the consumer and energy savings exceed the cost well within 12 months in a typical application.

Applications

Battery Powered Products

Rechargeable battery powered portable products such as mobile phones, tablet PCs, MP3 players and digital cameras have proliferated dramatically in recent years. The principles of operation discussed below apply to all these product categories although measured data is in a mobile phone application.

Even when fully charged, battery powered products still draw a small amount of load current from the output of the charger. By sensing the level of the output current it is therefore possible to establish the presence or not of a load. The LinkZero-LP IC shown in Figure 1 senses this condition from the primary side of the AC/DC power supply. Connected between the Drain (D) and Source (S) terminals of the LinkSwitcfh-LP is a MOSFET switch. The switching frequency of this MOSFET is varied in response to feedback information received at the FB pin. As the load connected to the DC Output is reduced, the switching frequency of the MOSFET switch is also reduced in proportion. As such the switching frequency of the LinkZero-LP is an indication of the load applied to the output of the power supply. Once the switching frequency goes below a threshold value (set to about 0.6% of maximum frequency) the IC detects this as a no load condition and initiates a very low power mode of operation called Power Down (PD) mode.

In PD mode, the internal circuitry of LinkZero-LP is completely shutdown and disconnected from the IC BYPASS (BP) pin supply rail apart from a voltage detection circuit connected to this pin. During the PD mode, the IC supply decoupling capacitor (CBP), which is connected to the internal IC supply rail, slowly discharges due to the current consumption of the internal voltage detection circuit. When CBP has discharged from its normal operating voltage of 5.85V down to a lower threshold of 3V, the IC wakes up and recharges CBP back up to 5.85V through a high voltage regulator internally connected between D and BP pins. The IC then briefly switches to check if the no load condition still exists on the output of the power supply and if so, re-enters PD mode and shuts down until CBP is again recharged back up to 5.85V

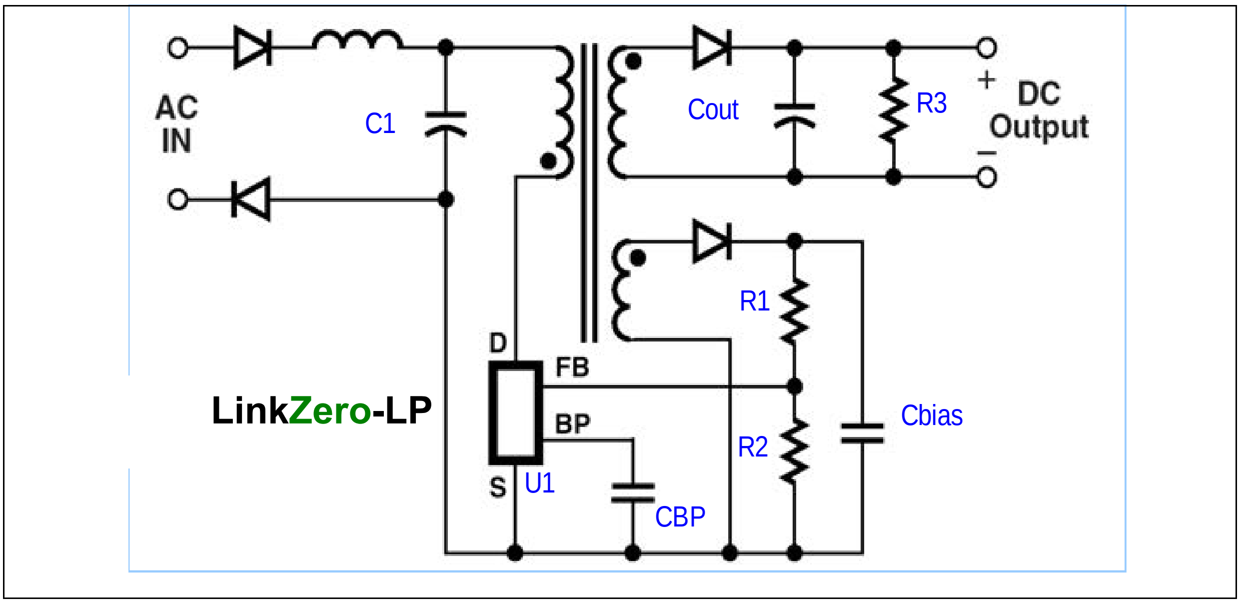


Figure 1 – LinkZero-LP AC/DC Power Supply Schematic

The time duration of each shutdown period while in PD mode is therefore governed by the rate at which CBP discharges from its operating voltage of 5.85V down to the reset threshold of 3V. The decoupling capacitor CBP therefore has the dual function of decoupling the IC supply rail and determining the shutdown period in PD mode. The user can therefore program this period to influence the no load consumption of the power supply. Figure 2 shows no load consumption in a 6V 350mA mobile phone charger. As can be seen the no load consumption is brought well below the target 5mW threshold with as little as 100nF CBP. If the mobile phone handset is reconnected at the start of the PD off period, the phone will not start to charge until that PD period has completed. So the duration of that period is a choice of the mobile phone manufacturer. Mobile phone manufacturers normally consider <1sec as a reasonable time duration before handset charging initiates which, from the data below, would allow the use of a 220nF CBP giving a PD shutdown period of approx 800msecs and a no load consumption at 230Vac of <3mW.

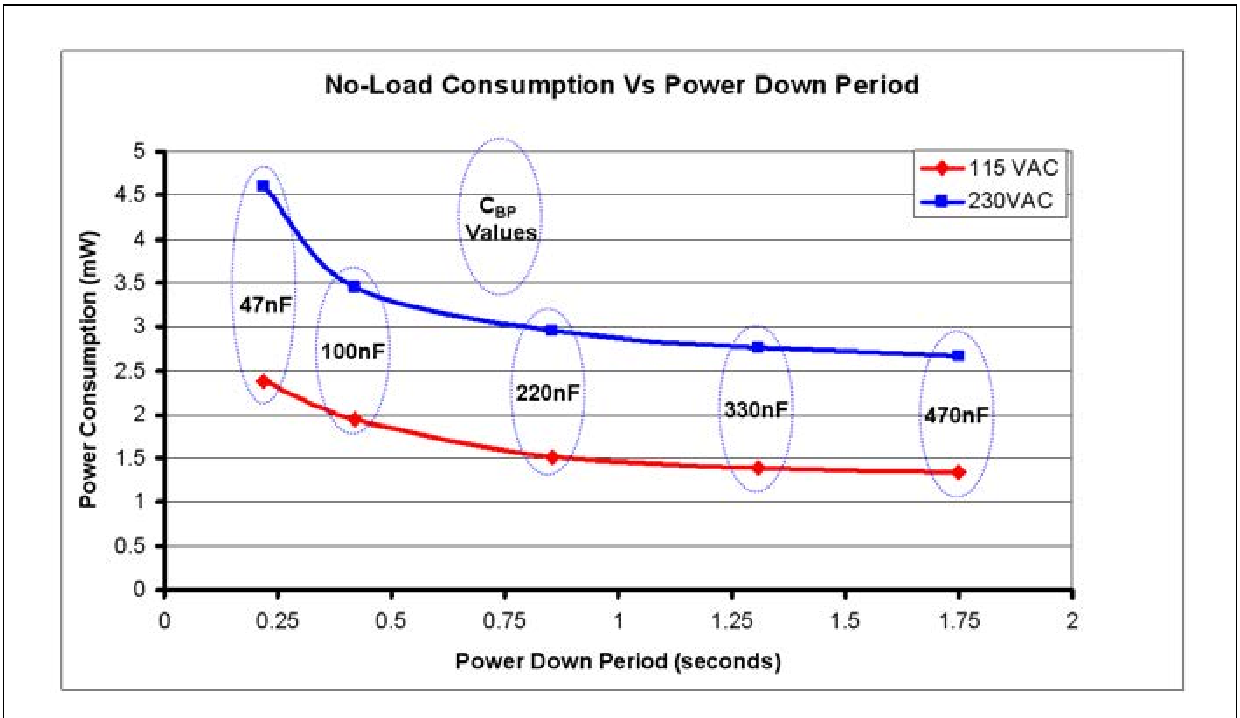


Figure 2 – No Load consumption vs Power Down period with various CBP values

It can be seen in Figure 1 that the LinkZero-LP IC can not influence no load consumption of the power supply input stage comprising bulk capacitor C1. C1 is typically a 400V electrolytic capacitor. Capacitors of this type do exhibit leakage current that will add to the consumption of the LinkZero-LP IC. It is therefore important to recognize the characteristics of such capacitors in making measurements on the circuit of Figure 1.

It is well documented that electrolytic capacitors can draw significant leakage current when voltage is first applied, in particular after prolonged storage without any applied voltage. When continuous voltage is applied, the leakage current decreases and reaches an almost constant steady-state value given by the equation[5].

$$I_L = kv \times \{(0.001 \times C_R \times V_R) + 3\} \mu A \qquad (1)$$

Where

I_L is the operating steady state capacitor leakage current

K_v is a factor governed by operating voltage as a percentage of rated voltage

C_R is the capacitor value in μF

V_R is the capacitor rated voltage in Volts

As an example, for the circuit of Figure 1 the value of C1 is 6.8μF with 400V rating.

When operating with an input voltage of 230Vac, at no load the voltage applied across C1 is the peak of the input AC voltage, or 325Vdc, since C1 is barely discharged under no load conditions. 325Vdc is 81% of the 400V rated voltage which results in a value of *Kv* in (1) of 0.4 [5].

Using these values:

$$I_L = 0.4 \times \{(0.001 \times 4.7 \times 400) + 3\} \mu A = 1.95 \mu A$$

At 325Vdc this is therefore a power loss of 0.63mW

Clearly this power consumption is a function of the capacitor value and therefore also the power rating of the power supply since higher power converters require larger input bulk storage capacitors. However, as Figure 3 shows, the power loss attributed to leakage in the input capacitors remains below 2.5mW up to 33uF capacitor values which would typically correspond to an ~20 Watt power supply. In principle therefore the LinkZero-LP operation allows for <5mW no load input power in much higher power converters than the one shown in Fig 1.

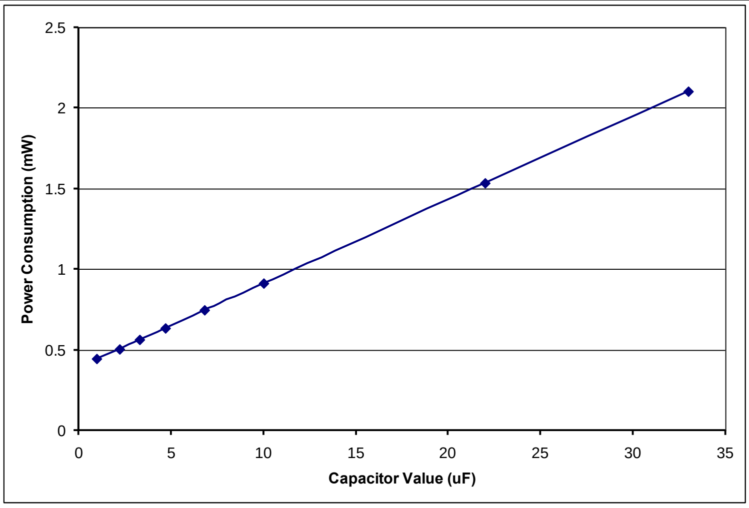


Figure 3 Power Consumption vs Capacitor value (400V Capacitor rating with 325Vdc applied)

The measurements of Figure 4 below show before and after no-load power consumption in the charger of Figure 1 using a standard control IC (LNK564) top and the LinkZero-LP below

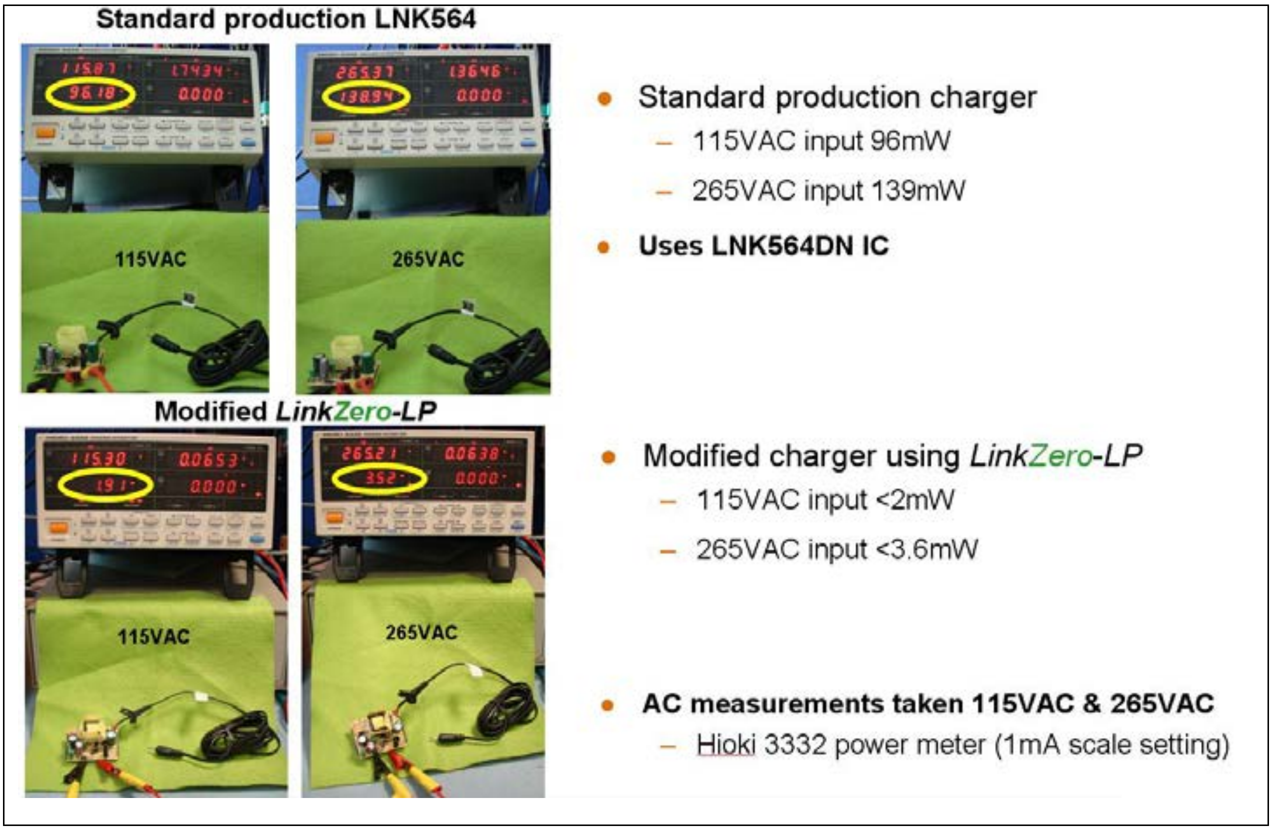


Figure 4 Comparative measured no-load results in real charger

Applications using IR Remote Control Wake Up

As well as applications in rechargeable battery powered products, the LinkZero-LP Power Down mode operation, where the device periodically wakes up, has applications in products using handheld IR remote controls to transition from standby to ON mode.

In applications such as TVs and set-top boxes for example, the Power Down mode of operation can be used to wake up the IR receiver every few hundred milliseconds to search for a remote controller turn on signal and if none is received, to shut the power supply back down. Such a condition is not truly no-load since the IR receiver does require power during the wake up events, however this operation can virtually eliminate standby consumption without the need for expensive relays or mechanical switches normally required to achieve the same.

White Goods and Other Domestic Appliances

Domestic appliances such as tumble dryers and coffee machines usually require the physical presence of a user to demand turn on or wake up from a standby condition. Even washing machines are often required to go into a standby mode following a timed washing cycle for example and are not required to wake up until a user replenishes detergent and sets the next washing cycle. Such applications can benefit from other members of the ‘Zero’ family of products as discussed below.

Figure 5 below shows a high level system schematic of a domestic appliance using three of the ‘Zero’ products, CAPZero, SENZero and LinkZero-AX

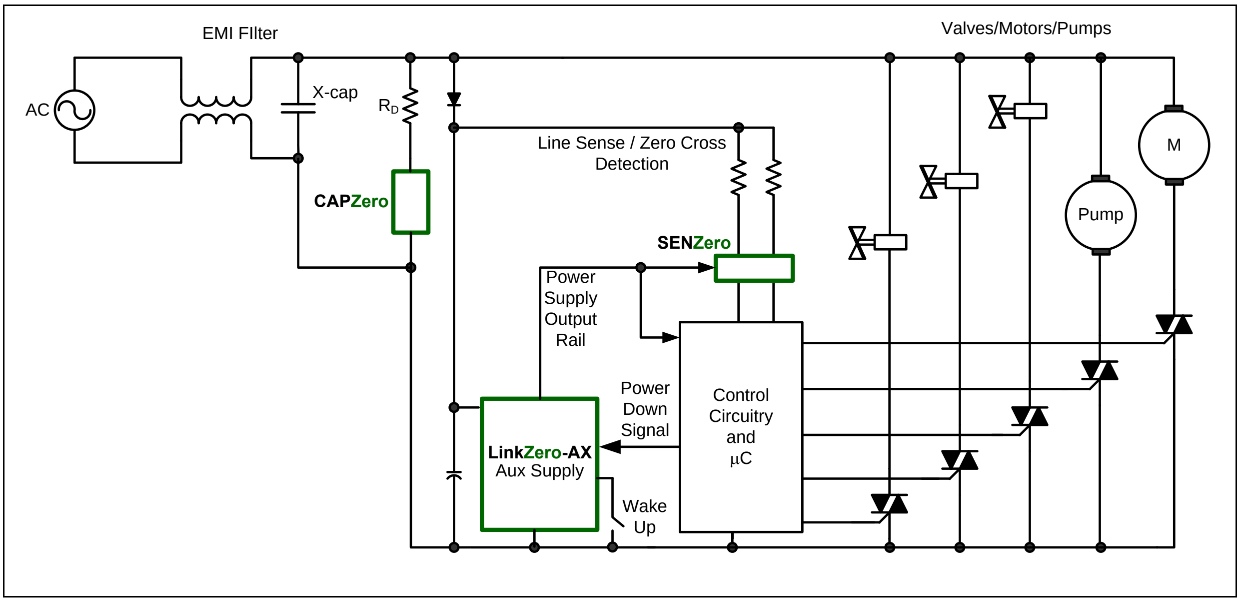


Figure 5 - Ultra low standby consumption domestic appliance configuration

The subsections below briefly describe the operation of each of the three key components contributing to the ultra low standby system performance,

LinkZero-AX

The LinkZero-AX differs from the operation of the LinkZero-LP described above in that, once set into the zero consumption Power Down mode, it does not wake up until a user applied reset/wake up signal is applied. Figure 6 shows the outline of this functionality in schematic form.

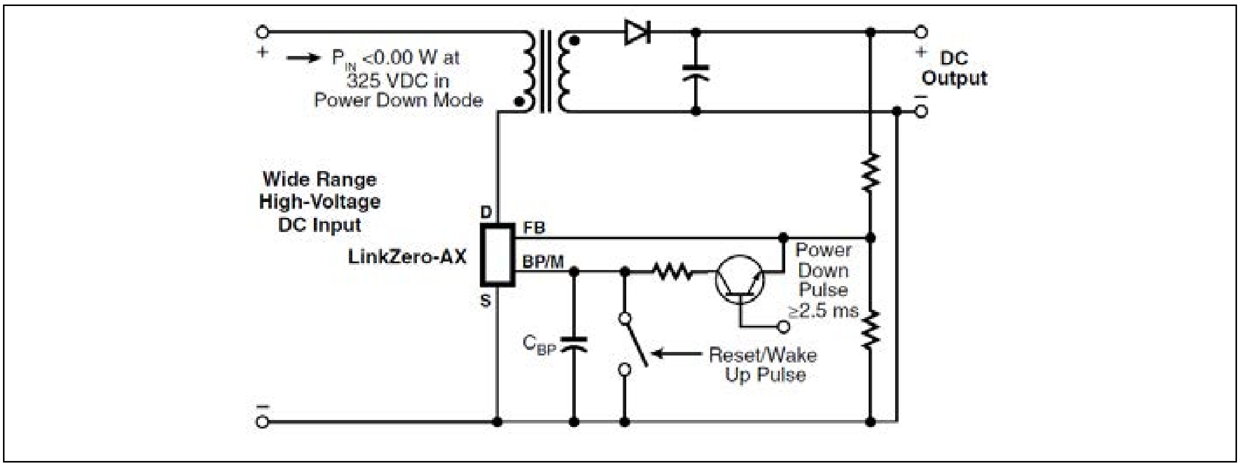


Figure 6 – LinkZero-AX Aux Supply

A power down pulse is applied by pulling the FB pin high for at least 2.5msecs. Such a signal is normally derived from the system microcontroller as indicated in the system diagram of Figure 5. This for example could be a signal generated at the end of a washing cycle in a washing machine and is sometimes referred to as a suicide signal since it is sent by the micro to turn off its own source of power. Once set into Power Down mode, the consumption from a rectified 230Vac supply is typically 3mW. In power down mode, although the IC appears in-active, it does actually maintain a voltage on the BP/M pin by drawing very small amounts of current through an internal regulator circuit connected between the Drain (D) and BYPASS/MULTI-FUNCTION (BP/M) pins. This allows the chip to remain active and await a wake up signal instructing it to turn the auxiliary power supply back on.

The wake up or reset signal is applied to BP/M pin as shown in Figure 6 and must pull down the voltage to a reset threshold set internally to 3V. The application of this pulse can be through a mechanical push-to-make or capacitively coupled switch as is popular in some applications. In Power Down mode, current can be drawn from the BP/M pin to power wake up circuitry though this current is derived from the high voltage rail via the D pin and will therefore increase power consumption accordingly. When released, the voltage on the BP/M pin is internally brought back to the normal operating voltage of 5.85V and normal power supply operation resumes.

CAPZero

The X-capacitor placed across the AC inlet terminals is a standard feature of EMI filter designs and filters differential mode current drawn by the various loads of the system. To meet international safety standards such as UL60950 [6], this X-capacitor must be discharged at a specified rate when the AC source is disconnected. This task is normally handled by one or more discharge resistors, shown as R_D in Figure 5. However the presence of R_D would normally continue to consume power from the AC source even when the appliance is in standby mode.

CAPZero is a two terminal IC that reduces the current flowing through R_D to <21.7μA (<5mW from a 230Vac source) when the AC source is still connected, but that allows the full discharge current to flow through R_D if the AC source is disconnected. The full functional description is beyond the scope of the present paper but a high level functional diagram of the CAPZero is shown in Figure 6 below. The bidirectional internal switches are rated to operate with up to 1000V in either polarity across the D1 and D2 pins. The internal control block controls the bidirectional switches to hold them off while AC is connected but when a loss of AC input voltage is detected for longer than a time of 22msecs, both internal switches are turned on enabling discharge of the external X-capacitor in either polarity through R1 and R2. The use of two resistors R1 and R2 in Figure 7 as compared to the single R_D in Figure 5 is simply a choice for the user based on the voltage rating of the discharge resistors. If surface mount resistors are used, then sometimes three or more series resistors are used. Regardless of the number or position of the resistors, the CAPZero functions as required. The CAPZero generates its own internal supply through the D1 and D2 pins and requires no external components to function. As such it can be inserted in existing systems simply by modifying the circuit board layout around the existing X-capacitor discharge resistors.

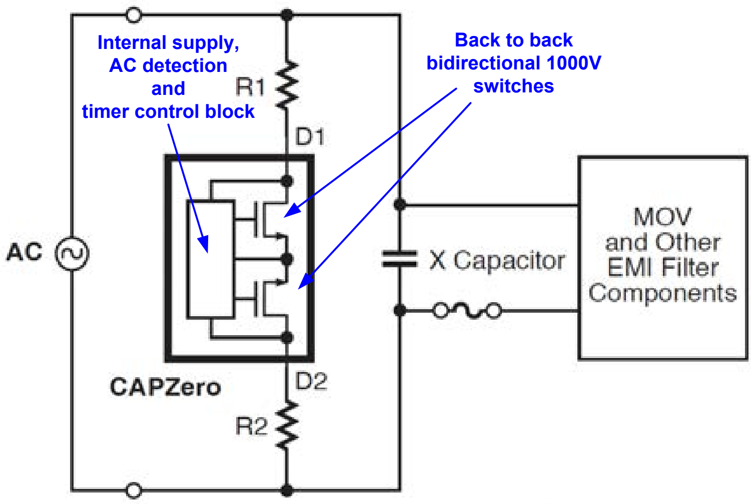


Figure 7 – CAPZero High Level Functional Diagram

SENZero

SENZero integrates 650V low leakage MOSFETs that are designed to be connected in series with resistors chains coupled to the high voltage input rails. In the example of Figure 5 the function of these resistor chains is marked as zero crossing detect and line sense as examples. Figure 8 shows the SEN012 IC integrating two such MOSFETs allowing 2 resistor chains to be disconnected when the system supply rail is disconnected. In the case of the system of Figure 4 of course the fact that the LinkZero-AX goes into Power Down mode, inherently means that the system power rail is lost which automatically turns off the high voltage MOSFETs within the SENZero.

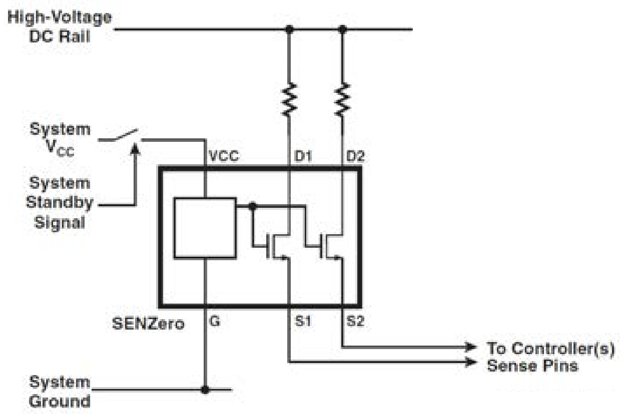


Figure 8 SENZero typical application

The leakage current through each MOSFET when in the off condition is <0.5mW from a rectified 230Vac input rail.

The measured results of Figure 9 were taken in a system of the type shown in Figure 5 with the various pump, valve and motor loads disconnected from the system. As such the results of Figure 9 isolate the losses associated with the system functions that LinkZero-AX, CAPZero and SENZero affect and show comparative consumption figures with and without these components. At all line conditions, the consumption is measured as <10mW total.

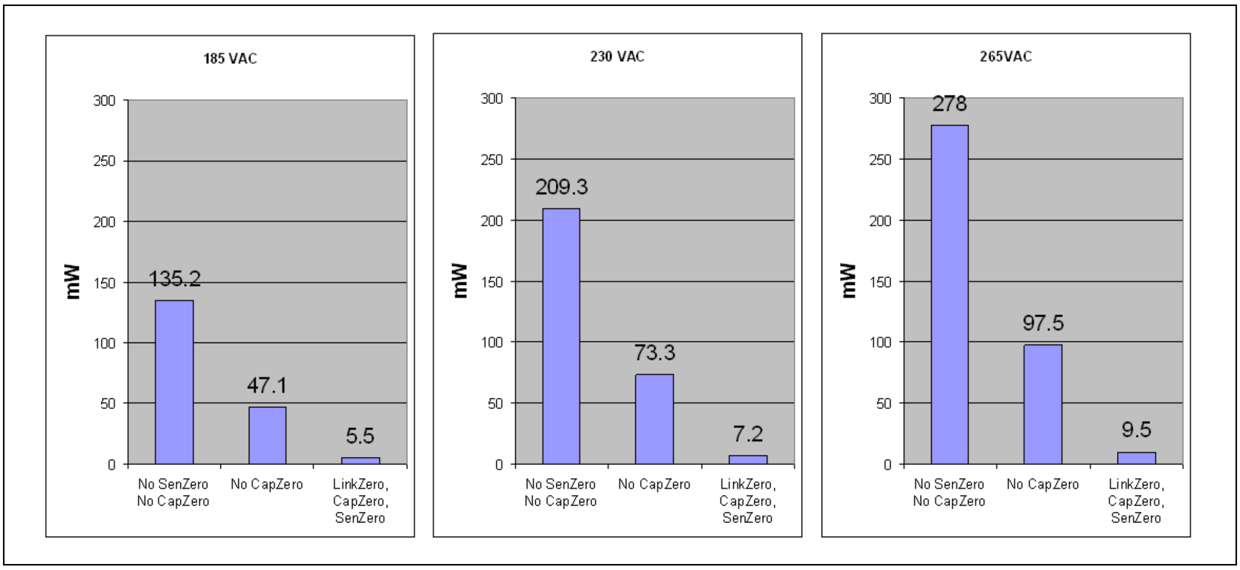


Figure 9 System Standby Power Consumption - comparative measurements

In a real system the presence of the various triac switches used to turn on and off the pump, valve and motor loads will add to the overall system leakage but nevertheless come well below the 50mW consumption necessary to claim 0.0W consumption for the complete system without the need to bulky and expensive relays or mechanical mains switches.

Conclusion

This paper has introduced a family of zero consumption ICs configurable to achieve zero consumption when used individually and <10mW even when used in combination in larger systems. These levels of performance have been demonstrated up to 265Vac covering the global range of continuous AC line voltages.

Application of these ICs requires no behavioral changes by the consumer using the end product while often reducing the size and weight of circuit boards by eliminating switches and relays.

Further work in the area of zero consumption will focus on other consumer applications such as Personal Computers and motor controls for domestic pumps. Industrial applications can also benefit from the simplicity brought by these ICs providing opportunities for energy savings in motor controls, factory automation process control panels and energy meters.

References

[1] UK Market Transformation Programme - Document BNXS15: Standby power consumption – domestic appliances.
Can be downloaded at http://efficient-products.defra.gov.uk/spm/download/document/id/590

[2] The ImpEE Universtiy of Cambridge Project report: Domestic Energy Use and Sustainability. Can be down loaded at: http://www-g.eng.cam.ac.uk/impee/topics/DomesticEnergy/files/Domestic%20Energy%20v2%20PDF.pdf

[3] http://www.wireless.att.com/cell-phone-service/accessory-details/index.jsp?q_sku=sku4780227&q_categoryid=cat1370037#fbid=_bhEgu7UYfV

[4] IEC62301 – Household electrical appliances – Measurement of standby power can be bought at: http://webstore.iec.ch/Webstore/webstore.nsf/Artnum_PK/44782

[5] Epcos Application Note: Aluminium Electrolytic Capacitors – General Technical Information document Nov 2008 p15-17. Can be downloaded at : http://www.epcos.com/web/generator/Web/Sections/ProductCatalog/Capacitors/AluminumElectrolytic/PDF/PDF__GeneralTechnicalInformation,property=Data__en.pdf;/PDF_GeneralTechnicalInformation.pdf

[6] UL60950-1 Information Technology Equipment – Safety Part 1 - General Requirements. Can be bought at: www.ul.com

Modified A^{++}- standard refrigerator with 30% reduction of energy consumption

Roland Brueniger
Swiss Federal Office of Energy

Stefan Stahl
awtec AG for Technology and Innovation

Abstract

In Europe 14% - 20% of the electrical energy in homes is consumed by various food cooling units. A small reduction in their energy consumption would have a significant impact on the global environment. In the last years, improvements in energy consumption of consumer refrigerators were mainly achieved with better and thicker insulation layers and improved tightening profiles at the edge of the doors. The potential of further improvements with better insulation are limited by factors like minimum useful capacity, usability, minimum cooling power and mostly the pressure on production cost. Therefore, additional ways of efficiency enhancement need to be found.

Thermodynamic analysis of actual compressor-based A++ refrigerators[1] indicated that the compressor is the component with the highest potential for improvement. Today's refrigerators run with a compressor at a fixed rotation speed, which is turned on and off by a thermostat. At room temperature and with closed doors the refrigerator runs about one fourth of the time. This mode of operation is inefficient because of the frequent start-up of the compressor, high internal losses due to the high flow rates and the large thermal gradient between the cooled volume and the cooling circuit.

A modified refrigerator was equipped with a compressor with variable revolution speed. This compressor can run at much lower speeds so that it is on up to 90% of the time. The compressor was controlled by a computer which at the same time collected various temperature data. The results showed an efficiency improvement of almost 30%.

Introduction

14% - 20% of the electricity consumed in homes is used by refrigerators and freezers. In Switzerland over 6 million appliances used for cooling foods consume about 2'500 GWh electricity per year [1]. If old or broken, cooling units are replaced by class A++ units, a lot of energy can be saved because these units only use half the energy of class A units. The step from A to A++ units can save 1'250 GWh/a. Our aim of cutting the energy consumption of A++ units in half can save another 600 GWh/a.

In the past years most of the development on refrigerators was devoted to improvement of the insulation. The following factors limit optimization:

- The ratio of storage volume to total volume must be within sensible boundaries
- Easy access for everyday use
- It must be possible to place warm foods inside
- Cooling circuit
- Low production costs

If a modern refrigerator is closely analyzed, it is obvious that the main optimization potential is in the compressor [2]. There are very few compressor suppliers worldwide (for instance Danfoss, Embraco) but many more refrigerator manufacturers, which purchase their compressors from the same place.

---

[1] The EU Directive 92/75/EC established an energy consumption labeling scheme. The directive was implemented by several other directives thus most white goods, light bulb packaging and cars must have an EU Energy Label clearly displayed when offered for sale or rent. The energy efficiency of the appliance is rated in terms of a set of energy efficiency classes from A to G on the label. In an attempt to keep up with advances in energy efficiency, A+ and A++ grades were later introduced for refrigeration products.

For the refrigerator manufacturer this means that they see very little possibility of differentiation in the compressor. Thus, this is not a field of innovation. At the same time the compressor manufacturers are confronted with lots of cost pressure by the refrigerator manufacturers. So their focus is the reduction of manufacturing costs and not technical innovation. The refrigerator manufacturers need energy efficient units to satisfy regulations and the market. However, the customers are not willing to pay much more for this innovation because the difference between a class A and a class A++ unit is not very visible.

Aim and approach of Project

An A++ refrigerator will be technically modified to show how much economization potential is in the compressor system.

Today's refrigerators run with a compressor at a fixed rotation speed. The compressor is turned on and off by a thermostat. At room temperature and with closed doors the refrigerator runs about one fourth of the time. This mode of operation is inefficient because of the frequent start-up of the compressor and the large thermal gradient between the cooled volume and the cooling circuit.

It is known out of information from literature [2] as well as past experiences that a compressor with variable rotation speed which runs most of the time can save more than 30% electricity compared to a standard compressor. In addition to having less start up cycles, the compressor with variable rotation speed runs at much lower speed so that the internal losses in the cooling circuit are significantly reduced. The thermal gradient between the cooling circuit and the cooled volume is also much smaller because the compressor is running most of the time.

Suitable compressors with variable rotation speed were identified on the market. Thus, the development of a new compressor was not needed.

Compressor manufacturers

The following European compressor manufacturers were originally considered as potential partners:

Danfoss, does not offer a compressor with variable rotation speed but would be willing to cooperate in the development of such a compressor.

Embraco, a large manufacturer producing also outside of Europe was quite cooperative. Embraco offers a range with variable rotation speed (VCC3). These compressors have already been installed in some high priced “Food Center Refrigerators”.

ACC also offers compressors with variable rotation speed which seem to be very efficient on paper; however they did not react to multiple inquiries from awtec.

It was decided to collaborate with Embraco on this project. It was hoped that this would make it easy to exchange a conventional compressor with a compressor with variable rotation speed. Unfortunately the collaboration ended up being quite complicated because of the geographical distances as well as language and cultural barriers (development in Italy, manufacturing and stock in Brazil). The flow of information to us was very limited: Important technical information which would have significantly simplified our project was not passed on. So it was not possible to get any information on production costs of the compressors.

Modification of standard refrigerator

The Electrolux Refrigerator

An Electrolux EK 244 11 refrigerator was chosen for this study. This is one of the most common class A++ refrigerators in Switzerland. It has a total volume of 241 l (215 l for cooled products, 26 l for frozen goods). The norm consumption is 173 kW per year. The Electrolux unit is built by Arbonia Forster with an EMX32CLC Embraco compressor.

Fig. 1 Electrolux EK 244 11

Compressors

The standard compressor EMX32CLC has a one phase induction motor. The EMX-line of compressors from Embraco is already energy optimized with higher motor efficiency and with special start up electronics. The EMX compressors save according to an information, communicated via an E-Mail, about 9% compared to the cheaper EMY line.

An Embraco VCC3 VEM X5C compressor with a 3-Phase EC motor was used for the modified refrigerator. The revolution speed can be varied from 1200-4500 RPM.

Fig. 2 shows the modified compressor with its inverter. A frequency generator was necessary to give a signal to the inverter (40 Hz – 150 Hz). Different compressors of the exact same type were used for experiments. They showed slightly different performance and needed different levels of fluid in the cooling circuit.

Fig. 2 Compressor with variable rotation speed Embraco VCC3 VEM X5C with inverter

Comparison of the compressors

The VCC3 VEM X5C compressor is the smallest compressor with variable rotation speed which is available from Embraco. The displacement is about 15% smaller than the standard compressor. Even so the VCC compressor has higher maximal power because it can run a higher revolution speed.

	Standard compressor	**Compressor with variable rotation speed**
Model	EMX32CLC	VCC3VEMX5C
Dispalcement	3.0 cm^3	2.6 cm^3
Maximal cooling power	73 W	100 W
COP (at 3000 RPM)	1.35	1.40

Table 1 comparison of the two compressors

The standard compressor reaches efficiency (COP) of 1.35 under standard conditions 2), the efficiency of the compressor with variable rotation speed lies between 1.21 and 1.4 depending on the rotation speed.

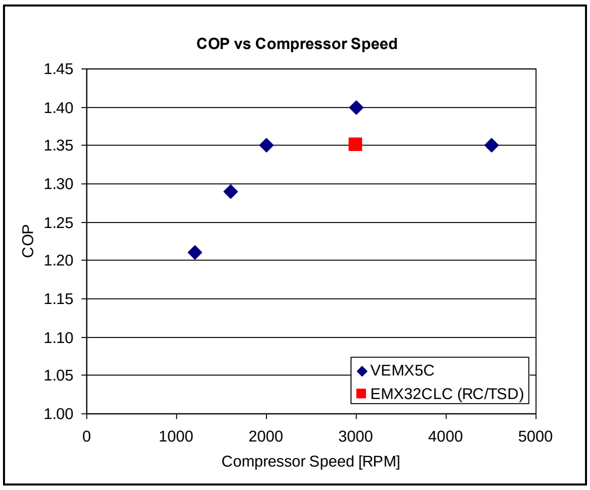


Fig. 3 COP of Standard compressor (red) and the compressor with variable rotation speed (blue) at different speeds

Fig. 3 shows the efficiency of the two compressor in dependence or the rotation speed. The modified refrigerator showed its best performance when the compressor was running at 1200 RPM, even though the COP of the compressor with variable rotation speed is only 1.21 compared to 1.35 for the standard compressor running at 3000 RPM. An optimization of the compressor efficiency at lower RPM could lead to a further increase in energy savings.

Installation and filling of the variable compressor

The variable compressor was installed in the modified refrigerator. In order to experiment with different levels of cooling fluid, a filling system was also integrated. Filling was possible with an accuracy of ±1g. We found that small changes in filling level had a significant influence on the temperature distribution between the cooling compartment and the freezing compartment as well as the overall performance of the refrigerator.

Fig. 4: Variable compressor with filling system

---

[2] CECOMAV: Evaporating temperature -25°C, condensing temperature 55°C

Temperature control and Data acquisition

It was our aim to compare the modified refrigerator with the original. In order to speed up the measurements, all tests were conducted with empty refrigerators. Thus, the tests do not comply with ISO 15502. The empty refrigerator has a lower heat capacity and reacts much faster to changes than a loaded refrigerator. This has no influence on the total energy consumption in our test modus.

The two refrigerators were built into a cabinet to simulate the installation in a typical Swiss kitchen (see Fig. 8). All tests were run in permanent direct comparison. This way it was not necessary to control the room temperature.

Temperature data and electrical consumption data were collected throughout the tests (Fig. 5) from the original unmodified refrigerator in parallel with the modified refrigerator.

Fig. 5: Measurement and control system

Fig. 6 Original refrigerator (left) and modified refrigerator (right) built into the same cabinet

Thermal elements measured the following temperatures in both refrigerators:

- Air temperature cooling compartment
- Wall temperature of cooling compartment
- Air temperature of freezing compartment
- Wall temperature of freezing compartment
- Compressor feed line
- Compressor backlash
- End of condenser

In addition, the following temperatures were measured:

- Room temperature
- Reference (ice water 0°C)

At the same time the electrical energy consumption of the two refrigerators was measured.

Software

The control and data acquisition software is based on NI LabView and runs on a Windows laptop which is connected to the data acquisition unit by USB, which reads out one thermal element every 2 seconds. This results in one data point every 32 seconds for each thermal element.

The temperature can be controlled in different modes:

- Fixed temperature with a hysteresis and fixed rotation speed of compressor
- Follower control, were the modified unit follows the temperature of the original unit by turning the compressor on and off at a fixed rotation speed
- Manual control

All three modes were used during optimization. All the tests presented here were run with the follower control. The data and control parameters are displayed in Lab View in order to get a fast overview (see screen shots Fig. 7 and Fig.8).

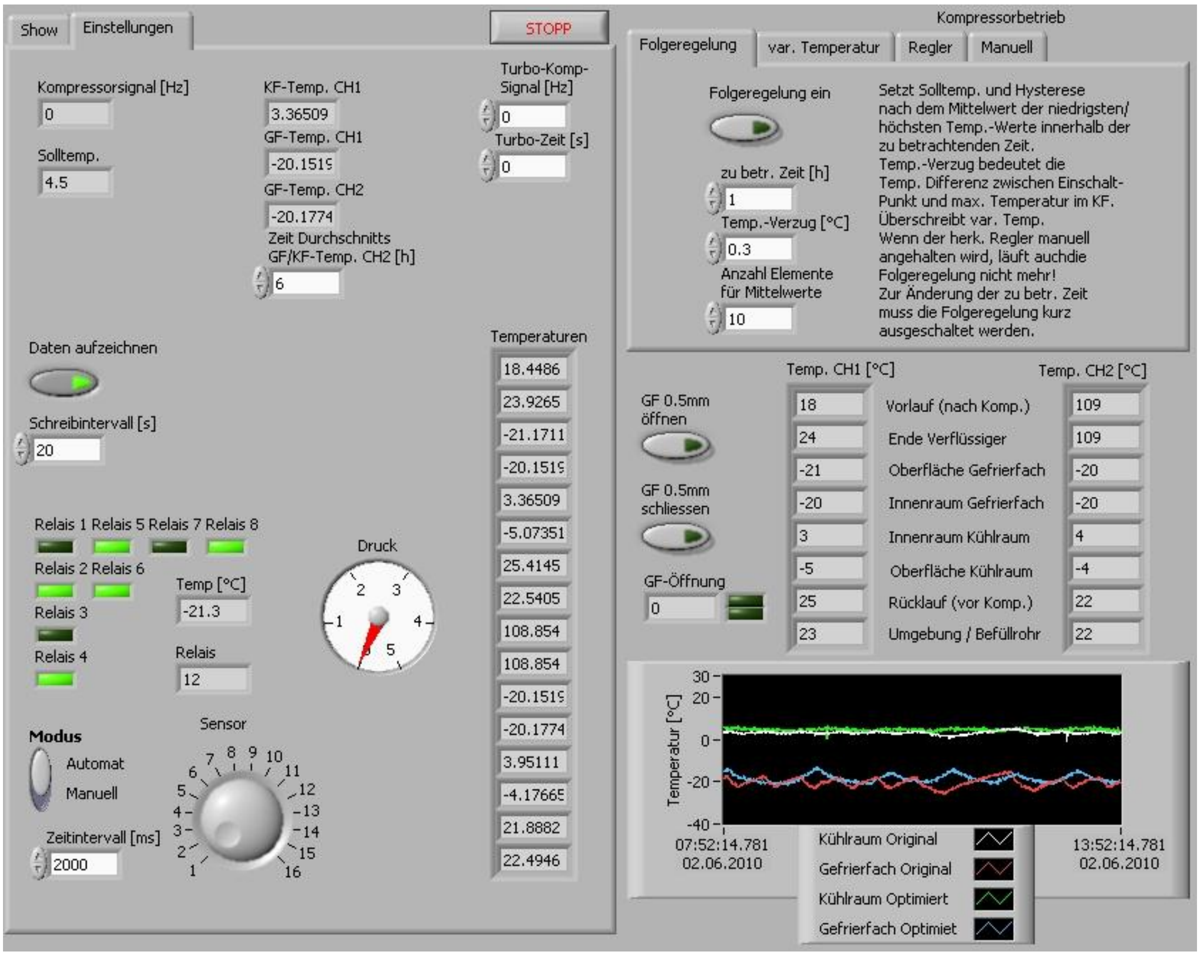


Fig. 7 Left: Temperature data (averaged out on top), right: Compressor control with follower control (the cooling compartment temperature of the modified refrigerator follows the cooling compartment of the original refrigerator)

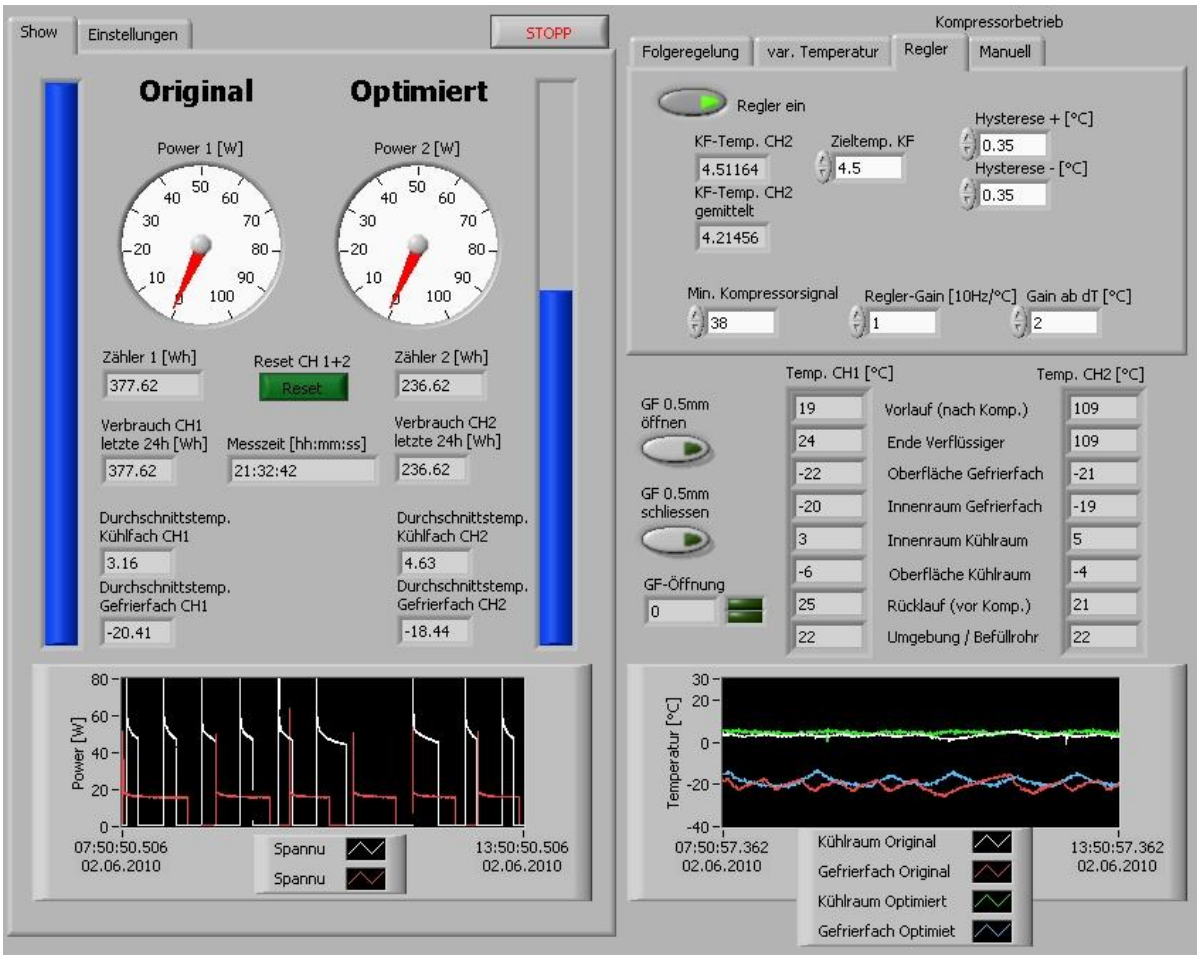


Fig.8 Left: Energy consumption overview for both refrigerators, right: compressor control of modified refrigerator

Results

Measurement procedure

A measurement was started after the refrigerator had stabilized with the new set of parameters. After a change in compressor rotation speed stabilization took a couple of hours. After a change in cooling, liquid stabilization took about one day. Fig. 9 gives an overview of the core data during a measurement. The temperature (left y-axis) and energy consumption (right y-axis) are plotted against the time (x-axis). The room temperature (green) is quite constant at about 27°C for the entire 40 hour period.

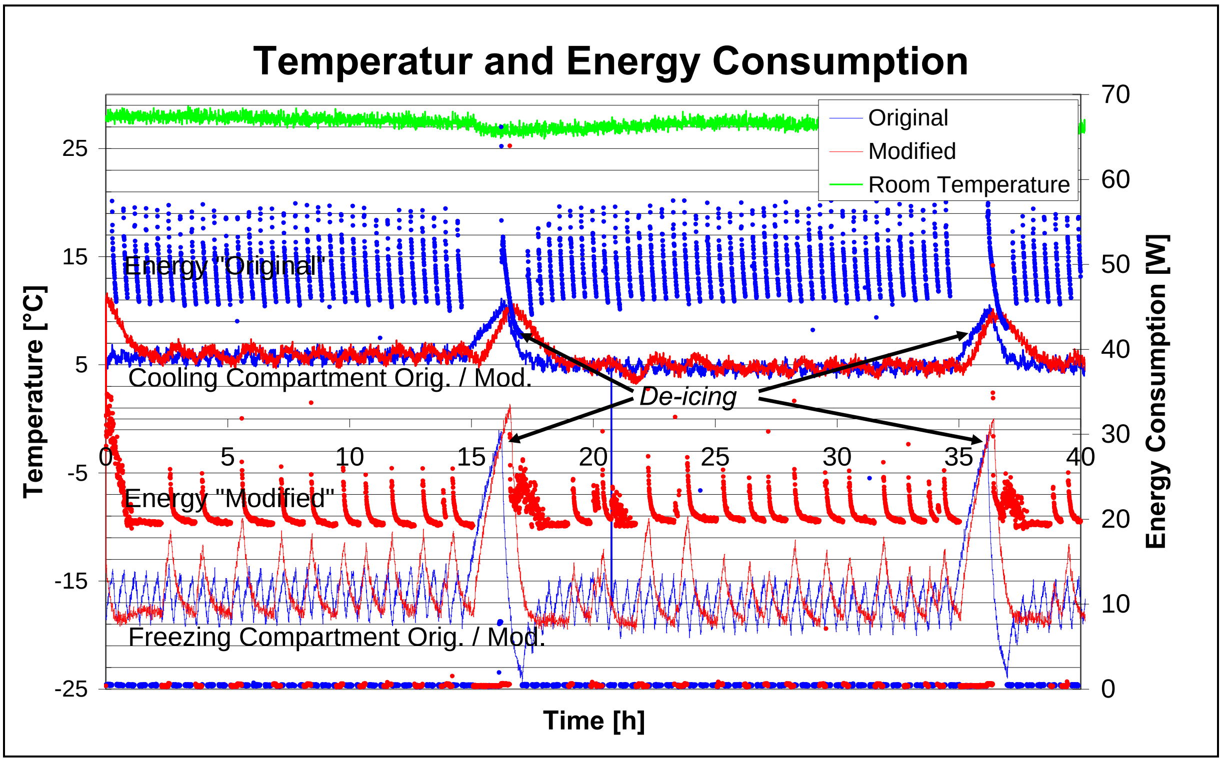


Fig. 9: Data acquisition with modified refrigerator running at 1600 RPM with 30 g of cooling fluid.

The original refrigerator (blue) was set at 5°C and its compressor always runs at 3000 RPM. The modified refrigerator (red) was set to run at constant compressor speed (1600 U/min) and match the cooling compartment temperature of the original refrigerator. In Fig. 9 it can be seen that this leads to very different running cycles for the two units. The modified refrigerator (red) runs about 75% of the time at low power, whereas the original refrigerator (blue) only runs about 25% of the time at much higher power. This leads to larger and longer temperature cycles in the cooling and freezing compartment for the modified refrigerator (red) compared to the original (blue) unit due to slower cooling with less power.

Temperature-corrected energy consumption

In practice, it was very difficult to exactly reproduce the temperatures of the cooling compartment and the freezing compartment of the original refrigerator. Thus, the energy consumption was corrected by the temperature difference between the two refrigerators. Fig. 10 shows the influence of temperature difference of the modified refrigerator running with 42 g of cooling liquid at 2400 RPM. The temperature difference is the sum of the temperature deviation in the cooling and freezing compartments. The x-axis shows the temperature deviation between the two refrigerators, whereas the y-axis shows the energy saving of the modified unit compared to the reference unit. A linear approach leads to the conclusion that a deviation of +1°C (compared to the original refrigerator) leads to about 5% less energy consumption (mathematically exact 4.7763%).

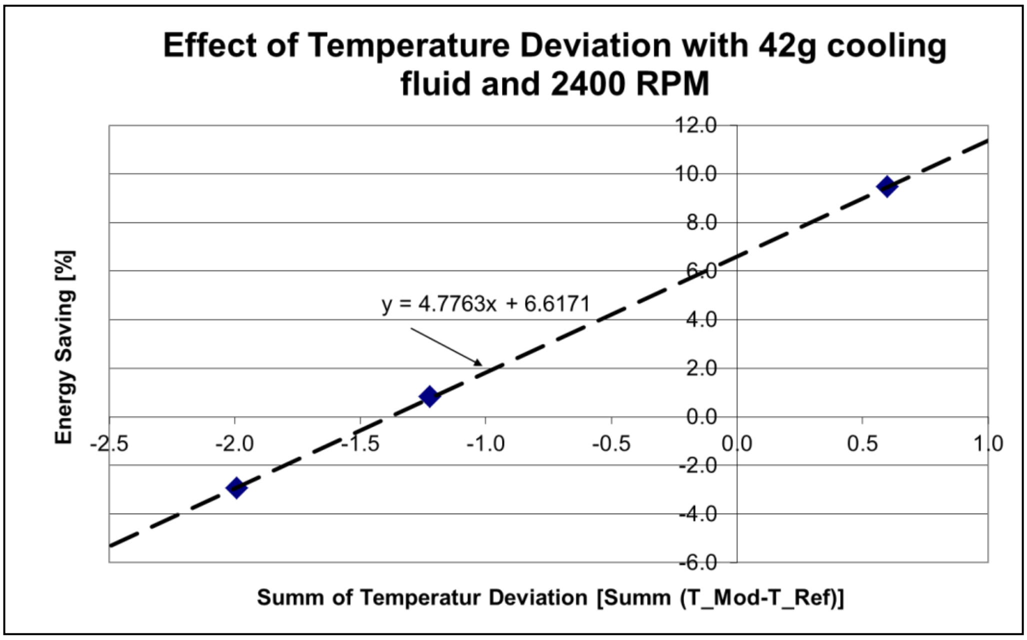


Fig. 10 Influence of the temperature deviation on the energy consumption

The corrected energy consumption was calculated as follows:

$$Consumption_{corrected} = Consumption_{measured} - 4.77 \cdot (\Delta T_{cooling} + \Delta T_{freezing})$$

Influence of the cooling fluid quantity

Tests were conducted at 1600 RPM to evaluate the optimal cooling liquid quantity for each compressor we used. Fig. 11 shows the effect of cooling fluid quantity on the consumed energy.

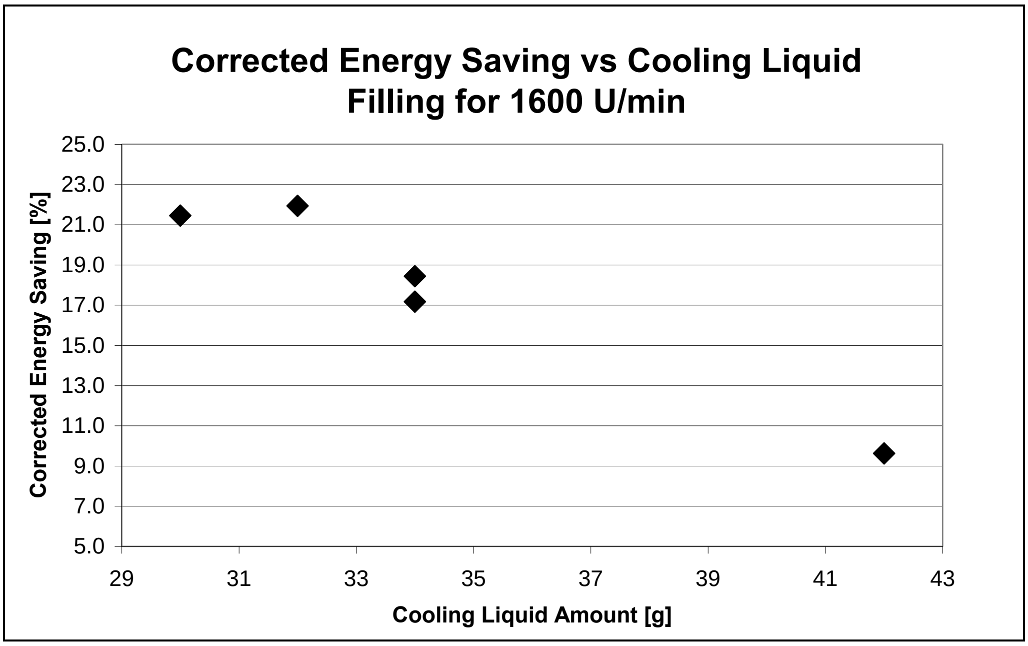


Fig. 11 Corrected energy consumption in dependence of the cooling liquid amount (for compressor 1)

It can be seen that with this compressor the highest saving in energy is achieved at low filling amounts of 30-32 g. Other compressors of the same model needed a bit more cooling liquid (34-36 g) for optimal performance. We do not know where this deviation between the compressors came from.

Influence of compressor rotation speed

Fig. 12 shows the influence of compressor speed on the energy consumption of the modified refrigerator run with 34 g cooling fluid. It can be seen that lower compressor speed leads to a significant energy saving. The lower energy input leads to smaller temperature gradients between the cooling circuit and the cooling compartments as well as the cooling circuit and the kitchen. This has the same effect as implementing a larger heat exchanger which leads to higher exergy efficiency. Further the lower compressor speed leads to fewer start-up cycles and less internal losses due to lower flow rates.

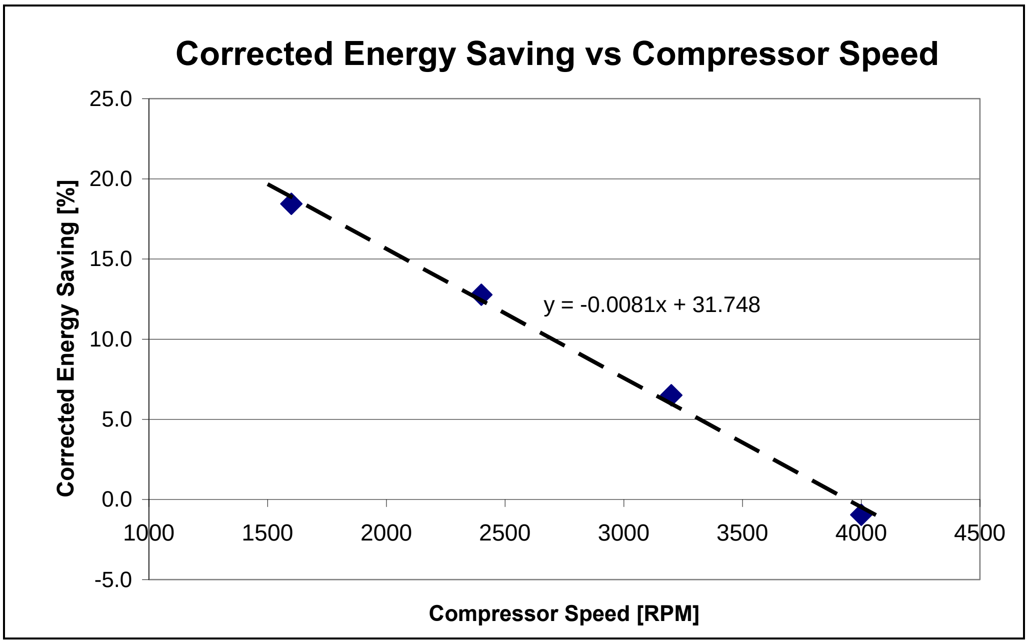


Fig. 12: Corrected energy consumption of the modified refrigerator run at different compressor speeds compared to the original refrigerator.

Running the compressor at 1600 RPM leads to energy saving of almost 20% compared to running the compressor at 4000 RPM. Of corse the compressor running at lower speeds is “ON” more. Fig. 13 shows the energy saving compared to the original refrigerator in dependence of the relative ON-time for 34 g cooling fluid. A relative ON-time of 2 means, that the modified refrigerator was running twice as much as the original.

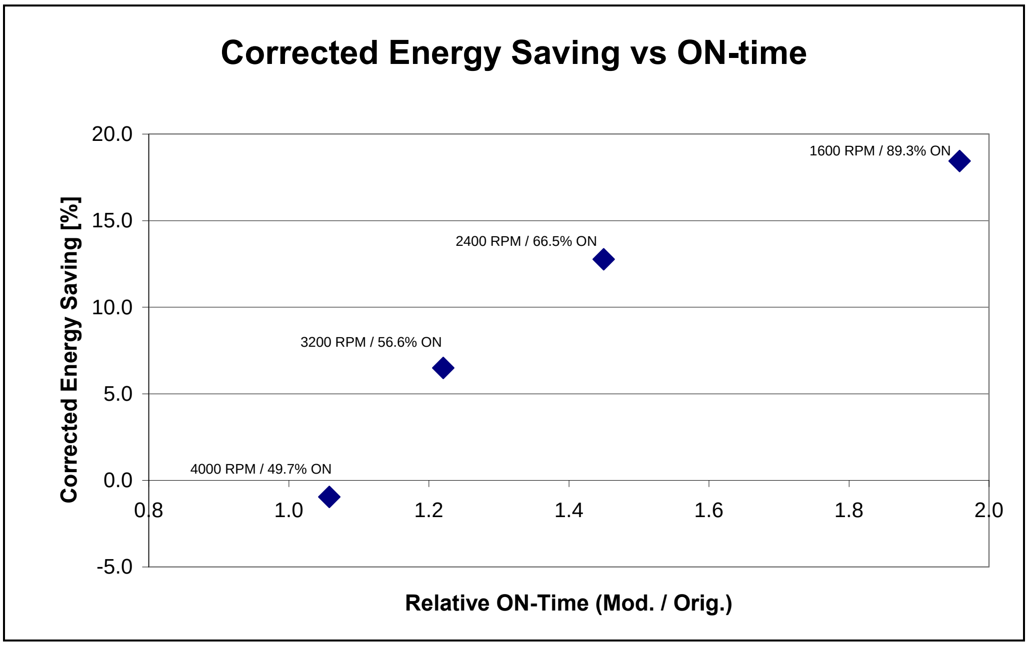


Fig. 13 Energy saving compared to the standard refrigerator for different relative ON-times

The higher the relative ON-time of the compressor the more energy is saved. The lowest energy was consumed at 1600 RPM where the compressor was running nearly 90% of the time (the original refrigerator was running almost 50% of the time because it was very warm in the lab).

Best performance

The best performance of the modified refrigerator was achieved when run at 1200 RPM. This resulted in a ON-time of 69% compared to 26% for the original refrigerator (factor 2.7). In this configuration 27% less electrical energy was consumed by the modified refrigerator. It shall be emphasized that the energy saving of 27% was achieved, even though the modified refrigerator has a stand-by consumption of 1.2 W compared to 0.2 W for the original refrigerator. We see much potential for even more energy saving.

Conclusion and next Steps

The results presented here show that much energy can be saved by small modifications on a household refrigerator. The most important modification was the installation of a compressor with variable rotation speed which can be run at much lower speed when the refrigerator just has to hold its temperature. Thus, the compressor is almost constantly running. The higher efficiency is mainly due to the following factors:

- Higher exergy efficiency due to smaller temperature gradients between the cooling circuit and the inside of the refrigerator as well as the cooling circuit and the kitchen
- Less (energy intensive) starting cycles
- Less internal losses due to lower flow rates

In direct comparison the modified refrigerator with its compressor running at just 1200 RPM consumes up to 27% less electricity than the original refrigerator running at 3000 RPM. Over the lifetime of the unit (about 15 years) this leads to financial savings of only about CHF 100.-. However, the global impact on the environment is significant.

In addition to using less electricity, the variable compressor is less loud when run at lower speed and can be run at very high speed when „cooling bursts“ are necessary, for instance when warm goods are placed inside.

It has been shown that a compressor with variable rotation speed can lead to a significant reduction in energy consumption. In the next project phase it must be shown that this can be achieved in an economic way (without a large increase in production costs).

As a next step a „close to series“ refrigerator shall be built with integrated compressor control. This refrigerator should then be tested to show that class A+++ can be achieved. A strong focus must lie on the optimization of manufacturing costs. For this it is essential to have a refrigerator manufacturer as a partner to make sure that we do not develop aside from the market. It is also essential to get the necessary technical information. A key player would be of interest because he could put more pressure on the compressor manufacturers and the market launch would have a larger global effect.

References

[1] *Bush, E. und Josephy, B.* (2007) „Hintergrundinformationen: Mehr Stromeffizienz mit A++ Kühl- und Gefriergeräten“, topten.ch/energie schweiz, http://www.topten.ch/uploads/images/download-files/HintergrundinformationenA++.pdf

[2] Philipp, J. (2000) „Optimierung von Haushaltskühlgeräten mittels numerischer Modellierung“, Dissertation der Fakultät Maschinenwesen der Technischen Universität Dresden, Forschungsberichte des Deutschen Kälte- und Klimatechnischen Vereins Nr. 65, Dezember 2000

Standby killers – Status and outlook after six years on the Danish market

Troels Fjordbak, Peter Karbo and Mads Kjær Jensen

IT Energy

Abstract

Background: Denmark uses around 34 TWh of electricity per year, with residential dwellings accounting for around 9.5 TWh of this figure. Standby consumption comprises around 9% of electricity used in homes. Savings around 150 GWh per year would be possible if every Danish home installed Standby killers, equivalent to 1.5% of household electricity consumption, or 0.5% of the total in Denmark.

Purpose: This paper describes the development in standby consumption in Danish homes in 2006 – 2010 based on in-deep surveys of 2000+ households every second year, and related energy savings through the use of Standby killers. A pending survey will be carried out late 2010 and the results and trends will be incorporated in the final paper.

Results: Penetration rates, usage patterns and energy savings will be calculated and further potentials will be calculated. General trends and patterns of the standby consumption are presented. Lot 26/task 4 for Eco-design requirements about Network standby losses, are considered. It will take into account the effects of the existing Eco-design standby-directive, and include a projection to 2020. The most significant result is a reduction in the potential standby savings from Standby killers, from 450 GWh (2006) to only 150 GWh (2010 estimate), due to the emerging effects of the Ecodesign directive.

Introduction

Through cooperation between main stakeholders in Danish Energy Sector – the Danish Energy Authority, Danish Energy Association, Energinet.dk and the Danish Electricity Savings Trust – a comprehensive and regularly updated database about electricity consumption in households has been established in the modelling framework known as ELMODEL-domestic. IT-Energy is responsible for running, maintaining and developing the model and data for the ELMODEL-domestic owners.

Series of appliance sales and stocks, annual consumptions, frequencies of use etc. have been collected since 1974. The market for white goods has been registered in the database ELDA since 1989 on individual model level, including test and labelling information from 1995 and onwards. Appliance test data for specific power levels have been collected since 1980s in Denmark, and in the latter years with supplements from other EU countries, USA and Australia since the appliances are the same or similar.

All data are used to analyse and forecast the Danish electricity consumption in households. A significant part of this is standby consumption. Until 2008 analysis and forecasts indicated that this part of the consumption was growing. The most recent forecasts take the eco-design directive for standby into account, thus rendering an expected reduction. But new scenarios for the development of appliances on standby in home networks can make the new down-trend for standby consumption turn around again.

Standby killer technology

In future, white standby killers might help offices and private households to save money. In October 2001, recognising that few people remember to turn off their computer equipment, Peter Karbo, a project manager at the Danish Energy Saving Trust, came up with the idea to develop a special auto-power-off plug bank, in the following denoted as a Standby killer. The Trust contacted the Danish Technological Institute for an assessment. This was the start of a cooperation to develop a functional standby killer that looked exactly like an ordinary plug bank. The special feature of the Standby killer is that it automatically turns off all plugged equipment once the controlling unit (e.g. a computer or TV) is switched off. The first prototype saw the light of day in December 2001.

Figure 2. The first Standby killer for connection via USB port.

The Trust wants to help new energy saving technologies and products gain a foothold in the market, with the intention that they should be both cheap and widely available. In order to promote the standby killer the Trust produced finished product specifications developed in cooperation with the Danish Technology Institute, which carried out the initial development work. The final design, documentation and a prototype were unveiled in August 2003. The Trust's contribution ended there, and the design was offered to the market as freeware. All the material was made available to producers showing an interest. The technical documents can be downloaded free of charge from the Trust's website.

Initially, three Danish suppliers launched standby killers for PCs at Christmas 2003 [4].These versions were all standby killers for connection to a PC via the USB port, which detects whether the port has power or not. If the PC was off and there was no power to the USB port, the standby killer would be switched off by a relay. All the other peripherals, which would normally have to be switched off individually, were now switched off automatically as a result of being plugged into the standby killer.

Over the following years this technological solution caused some problems as new PC motherboards with continually powered USB ports were introduced onto the market. Then Windows Vista arrived, which always keeps USB ports continually powered, so actually the market for USB-powered standby killers is nearing its end. In the meantime, standby killers were launched for use with the TV and associated devices connected on the "master/slave" principle. The TV is plugged into the master socket. Here, the power is detected and a relay will turn off all the slave plugs if the power supply falls below a specified level – typically 20 Watt.

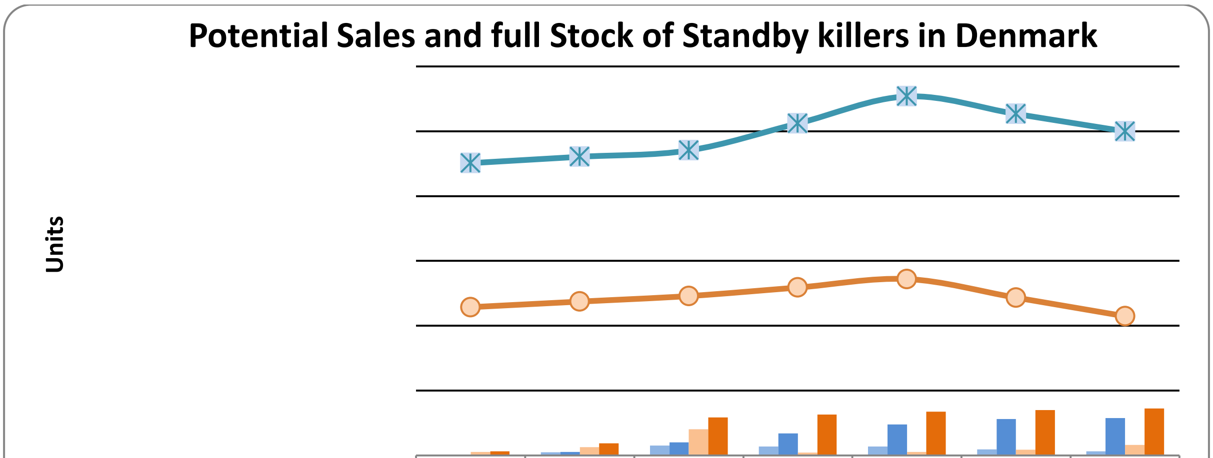
Figure 3. Examples of TV standby killer variants.

These worked well in many cases, but to keep production prices low the technical solution was fairly simple. This meant that in some cases the standby killer were "cheated" into believing that the power level was very high because of a very low power factor, so they did not turn off the slaves, thereby failing to do the job they were designed to do [5].

The problems for TV standby killer are expected to increase with the current technology, as increasing numbers of new TVs with a very low standby power use flood into homes.

A new generation of standby killers were developed detecting standby power use for any device plugged into the master socket, which means that they can work with all devices as the master, including PCs, notebooks, TVs, audio equipment, etc. At the same time, the energy consumption of new standby killers itself was reduced to almost nothing – in contrast with previous consumption levels of the old TV standby killers, which was 0.5–1.5 Watt. More details in [15].

Figure 4. Estimated potential sales and stock of Standby killers.



	2004	2005	2006	2007	2008	2009	2010
Est. sales, TV-plugs	5000	45000	151000	137000	136000	90000	63000
Stock (EB), TV plugs	5000	50000	201000	338000	474000	559000	577000
Est. sales, PC-plugs	50000	125000	400000	43000	54000	86000	162000
Stock (EB), PC-plugs	61000	186000	586000	629000	672000	697000	723000
Full TV-plug stock potential	4508000	4606000	4704000	5120500	5537000	5267500	4998000
Full PC-plug stock potential	2285850	2371600	2457350	2588425	2719500	2432850	2146200

The figure illustrates that there is still some way to go before all potential PCs and TVs are equipped with Standby killers, though the total stock of PC's and TV's are slightly declining in 2009 and 2010. In fact the ownership levels for TV fell from 2,24 to 2,04 per home, from 2008 to 2010. This remarkable result is assumed to be due to a final disposal of the old CRT-types. For PC's the declining ownership is due to higher levels for laptops.

From questionnaires in Denmark 2006[3], 2008 [13], and 2010 [14] the stated ownership levels in Denmark for Standby killers were:

Table 1. Ownership and potential share.

Year	TV-plugs, ownership	TV-plugs Pot. share	PC-plugs, ownership	PC-plugs Pot. share
2004	0.2%	0.1%	2.5%	2.7%
2005	2.0%	1.1%	7.6%	7.8%
2006	8.2%	4.3%	23.9%	23.8%
2007	12.9%	6.1%	24.4%	22.4%
2008	17.5%	8.0%	24.8%	21.0%
2009	19.3%	9.1%	25.6%	25.5%
2010	21.0%	10.3%	26.3%	30.1%

It appears that although on average one fifth of Danish households own a TV Standby killer in 2010, only about one tenth of TVs are equipped with such a plug. For PC's about every third is equipped with a standby killer, a fraction maintained partly by the fact that ownership levels for stationary PC's are dropping.

Standby definitions

The definitions used in this document are the same as the definitions in the EU eco-design requirements for standby and off-mode electric power consumption.

The definitions vary from earlier, most significantly by having **no sleep mode** definition – sleep mode is now a part of standby, and (some of) the old standby mode is now OFF-mode. This means some of the previously collected power mode data are obsolete and/or ambiguous.

Data are treated most carefully to overcome these translational problems, but for some appliances the definition change results in no data for some of the modes. This is indicated in the following tables by a – (dash). It should be emphasized, that a dash does not necessarily mean the appliance does not have the specific power mode, but only that measurements are missing at the present.

Power levels

From the on-going maintenance of the Danish stock model ELMODEL-bolig [1] and recent measurements conducted in IEE-project SELINA [12], we operate with these power level figures:

Table 1. Power levels for PC-related appliances in homes (Watts), 'ELMODEL-bolig 2006-2010' [1] and SELINA [12].

PC-related appliances	**Average Power level 2006**		**Average Power level 2008**		**Average Power level 2010**	
Appliance	Standby	Soft Off	Standby	Soft Off	Standby	Soft Off
	Watt	Watt	Watt	Watt	Watt	Watt
Desktop PC	5.7	4.1	5.9	1.4	2.2	2.9
Laptop PC	1.7	1.0	0.9	0.5	0.9	0.6
Monitor CRT 14-15"	3.1	0.0	3.1	0.0	3.1	0.0
Monitor CRT 17"	3.2	1.2	3.2	1.2	3.2	1.2
Monitor CRT >17"	4.0	1.2	4.0	1.2	4.0	1.2

Monitor LCD 14-15"	4.0	1.8	2.2	1.1	0.4	0.3
Monitor LCD 17"	3.1	2.1	1.8	1.3	0.6	0.4
Monitor LCD >17"	3.9	2.1	2.2	1.2	0.5	0.4
Printer. inkjet	1.3	0.6	0.4	0.4	0.9	0.9
Printer. laser	16.7	5.0	1.1	1.1	1.1	1.1
Scanner	3.5	3.0	2.4	1.2	1.4	0.1
Multifct. machine Inkjet	2.9	0.8	6.4	0.9	9.9	0.7
Multifct. machine Laser	17.8	3.5	13.8	0.9	9.9	0.7
Router/switch	9.3	-	7.4	-	5.4	-
ADSL modem	9.4	-	7.4	-	5.4	-
ISDN modem	8.3	-	6.9	-	5.4	-
Wireless network	7.0	-	6.2	-	5.4	-
Speakers	4.8	3.0	4.9	1.7	3.0	0.7
External modem	8.0	3.0	7.2	2.2	6.3	1.1
External hard disk	7.7	3.0	7.7	2.1	5.0	1.3

Table 2. Power levels for TV-related appliances (Watts), 'ELMODEL-bolig 2006-2010' [1] and SELINA [12].

TV-related appliances	**Average Power level 2006**		**Average Power level 2008**		**Average Power level 2010**	
Appliance	Standby	Soft Off	Standby	Soft Off	Standby	Soft Off
	Watt	Watt	Watt	Watt	Watt	Watt
Colour TV CRT 14"	3.7	3.7	3.7	0.7	2.7	0.0
Colour TV CRT 26"	3.0	3.0	2.8	0.7	2.7	0.0
Colour TV LCD 26"	8.0	0.8	1.9	0.3	0.8	0.2
Colour TV LCD 40"	3.1	0.5	1.9	0.3	0.8	0.2
Colour TV Plasma 42"	3.1	0.6	1.6	0.3	0.4	0.2
Colour TV Plasma 50"	3.1	0.6	1.6	0.3	0.4	0.2
VCR	3.0	1.2	2.9	-	2.3	-
DVD player	4.5	4.7	0.9	0.5	1.3	0.7
DVD player/recorder	6.1	6.1	4.6	0.7	4.9	1.0
Set-top-boxes	10.0	-	3.2	0.1	5.1	0.1
Satellite dishes	4.7	-	-	-	-	-
Antenna amplifier	3.6	-	1.0	1.0	0.2	0.2
Gaming machines	68.9	1.6	23.9	0.5	1.3	0.0
Surround sound	5.0	5.0	4.9	0.9	4.7	0.7
Projector/home cinema	5.1	5.1	1.6	0.9	1.7	0.9

Also from the on-going maintenance of the Danish stock model ELMODEL-bolig [1] and specifically the biannual questionnaires ([3], [13], [14]) conducted in the project, we have answers about which appliances that are plugged into the Standby killers:

Table 3. Appliances plugged in PC Standby killer 1.

Appliances plugged	**2006 %**	**2008 %**	**2010 %**
Printer	88.4	88.9	83.6
Speakers	84.8	70.6	70.4
Scanner	51.3	46.5	50.3
Router/hub/switch	43.0	40.8	63.0
External hard drive	28.0	31.7	34.7
Screen	17.3	-	7.5

Lighting	8.8	-	9.8
Modem	3.6	-	-
Mouse	2.4	-	1.0
Laptop	1.6	-	0.4
DVD	1.2	-	0.5
TV/VCR	0.8	-	3.0
Other	4.0	25.9	5.1
Total	335.3	305.0	329.3

Table 4. Appliances plugged in PC Standby killer 2+.

Appliances plugged	2006 %	2008 %	2010 %
Speakers	70.7	71.3	48.8
Printer	58.5	51.6	26.1
Scanner	35.8	26.0	14.1
External HHD	22.2	32.2	16.2
Router/hub/switch	18.8	26.2	40.1
Screen	15.5	-	4.5
Lighting	4.8	-	3.0
Modem	2.9	-	0.6
Mouse	1.0	-	2.2
Other	1.9	26.6	13.7
Total	232.1	234.0	169.3

Thus an average of 3.4 appliances plugged per socket, in addition to the controlling PC. To compare with the total ownership, e.g. for printers, one should multiply the 88.4% with the PC plug penetration of 25%, yielding a total of 22% of the printers plugged into a Standby killer. This leaves about 88% of the total 110% ownership (i.e.1.1 printers in average per home) not plugged in a Standby killer.

Table 5. Appliances plugged in TV Standby killer 1.

Appliances plugged	2006 %	2008 %	2010 %
DVD	80.2	82.7	77.0
VCR	70.8	82.0	33.0
Surround sound	31.0	21.1	19.0
Set-top box	20.4	27.2	27.0
Games machine	14.9	21.0	33.0
Audio equipment	13.9	-	4.0
Media centre	7.8	-	-
Lighting	7.0	-	1.0
Other	2.6	29.0	5.0
Total	248.7	263.1	199.0

Table 6. Appliances plugged in TV Standby killer 2+.

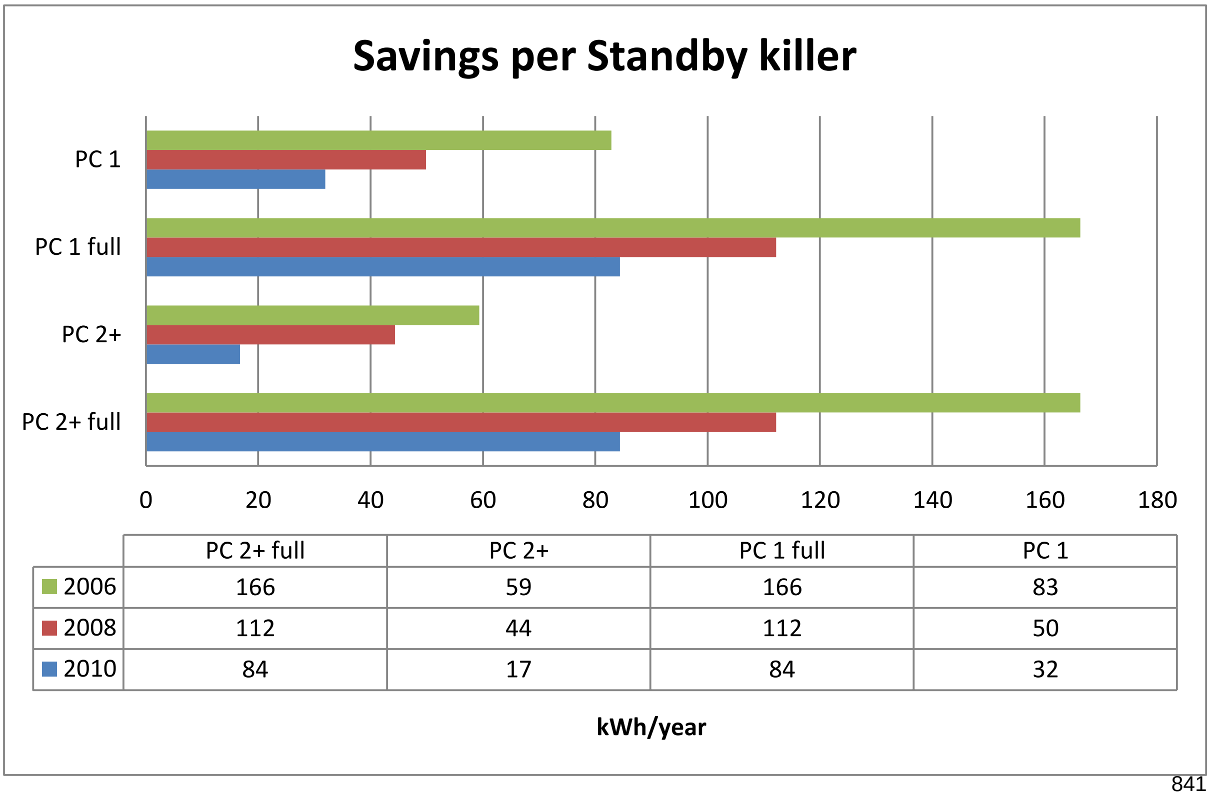
Appliances plugged	2006 %	2008 %	2010 %
DVD	36.3	59.0	52.4
Set-top box	35.5	14.3	15.5
Audio equipment	27.7	-	2.5
VCR	24.5	43.4	22.3
Surround sound	13.3	16.9	8.6
Games machine	8.4	19.0	33.7
Media centre	5.5	-	-
Lighting	5.5	-	1.6
Other	2.8	52.2	9.3
Total	159.7	204.8	145.9

Derived savings

By using the power levels with usage hours from the same source, it is possible to analyse how the standby killers can affect standby consumption. Naturally this depends on what is plugged into the standby killer. Reference [1] provides a calculation of this in 2006, for Standby killer 1 and 2+, for PC and TV. Repeating these calculations for 2008 and 2010, the following series can be obtained:

Figure 5. PC Standby killer savings estimates.

Figure 5 shows the detailed energy savings for PC Standby killer 1 and "2+". For 2006, on average, killer 1 saves 83 kWh/year, additional sockets in average 59 kWh/year. These figures develop to only 32 and 17 kWh/year respectively, for Killer 1 and 2+ in 2010.



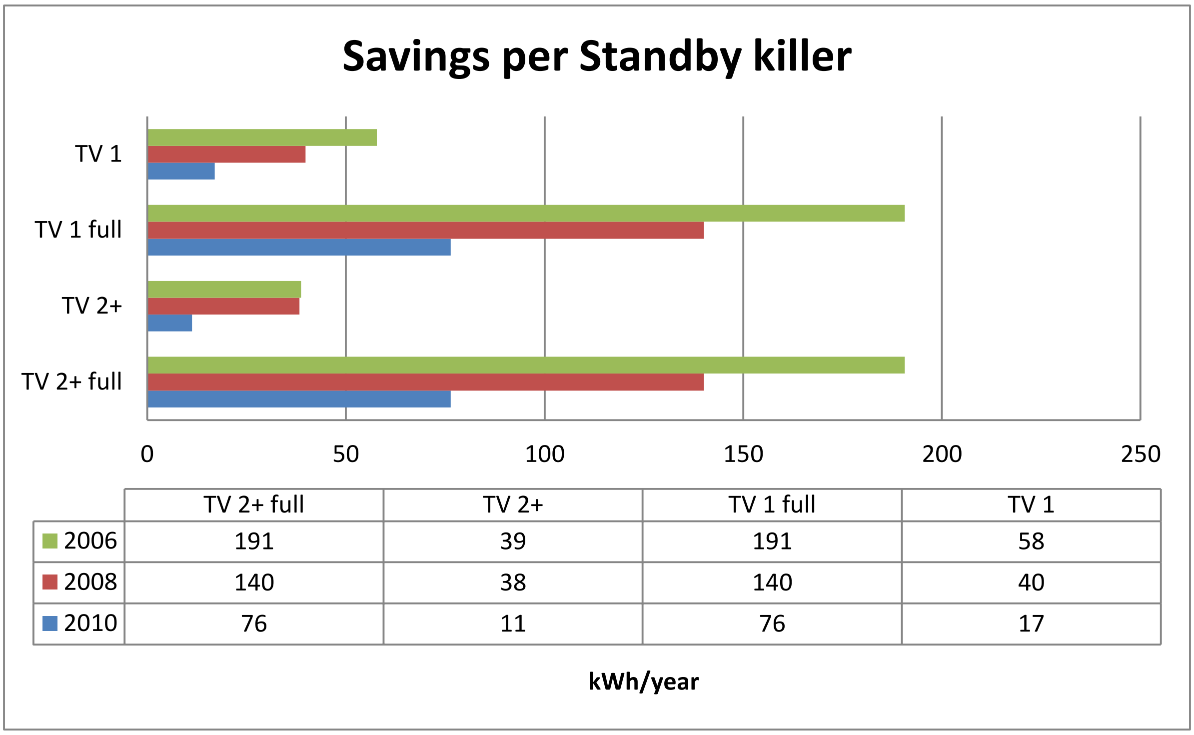


Figure 6. TV Standby killer savings estimates.

Figure 6 shows the detailed energy savings for TV Standby killer 1, and 2+ respectively. For 2006, on average Killer 1 saves 58 kWh/year, additional sockets in average 39 kWh/year. For 2010, the average Killer 1 saves only 17 kWh/year, additional sockets in average 11 kWh/year.

The estimated savings per Standby killer leads to the following National impact:

Table 7. Achieved and potential savings.

Year	Stock TV Killer 1	Stock TV Killer 2+	Stock PC Killer 1	Stock PC Killer 2+	Total savings	Total potential savings	Fraction
	Units	Units	Units	Units	GWh/year	GWh/year	%
2004	5,000	0	61,000	0	5.8	439	1.3
2005	48,387	1,613	180,000	6,000	19.6	451	4.3
2006	151,956	49,044	415,000	171,000	59.7	463	12.9
2007	208,360	129,291	462,721	166,356	56.1	428	13,1
2008	264,763	209,537	510,442	161,711	52.5	392	13,4
2009	351,609	174,221	514,443	183,171	42.8	272	15,7
2010	438,454	138,905	518,444	204,630	33.0	152	21,7

At present, almost one quarter of potential savings with standby killers has been achieved. The aggregate savings from 2004 to 2010 sums to about 270 GWh, corresponding to ca. 135.000 tons of CO_2 from Danish power plants.

Scenarios for standby in Denmark

The stock model ELMODEL-domestic can produce projections of the Danish household electricity consumption on appliance level, i.e. total consumption for washing machines in Denmark etc. Also, the distinguishing between On-mode and Standby-mode is a part of the model stratification. Furthermore, variations of appliance on/standby power levels, ownership development and frequency of use can be made in the model framework, leading to various scenarios simulating different assumptions for future developments.

In the following, three scenarios are outlined, all three focused on the Standby consumption. The first is the base scenario, i.e. most likely development on the basis of today's knowledge about trends in ownership, usage and technology, and current legislation (1). This is compared with a situation without the Ecodesign directive for Standby, to get an idea of the impact (in Denmark) of the directive (2).

The third scenario is a simulation of the development of network standby being much higher than expected now (3). This is done both as simulating a higher standby power limit (since no network standby ecodesign directive is in place at this time), and simulating a much higher stock of appliances being able to connect through wireless network adapters.

Sales and stock

The sales of consumer electronics, which comprises the major part of the standby appliance stock, is simulated in the model as an equal split on different Wattage groups, from 0,1 - 0,3 Watts and ending with a group from 6 Watts and above. Assuming a normal distributed 4 years lifespan of these products, the following stock development can be calculated:

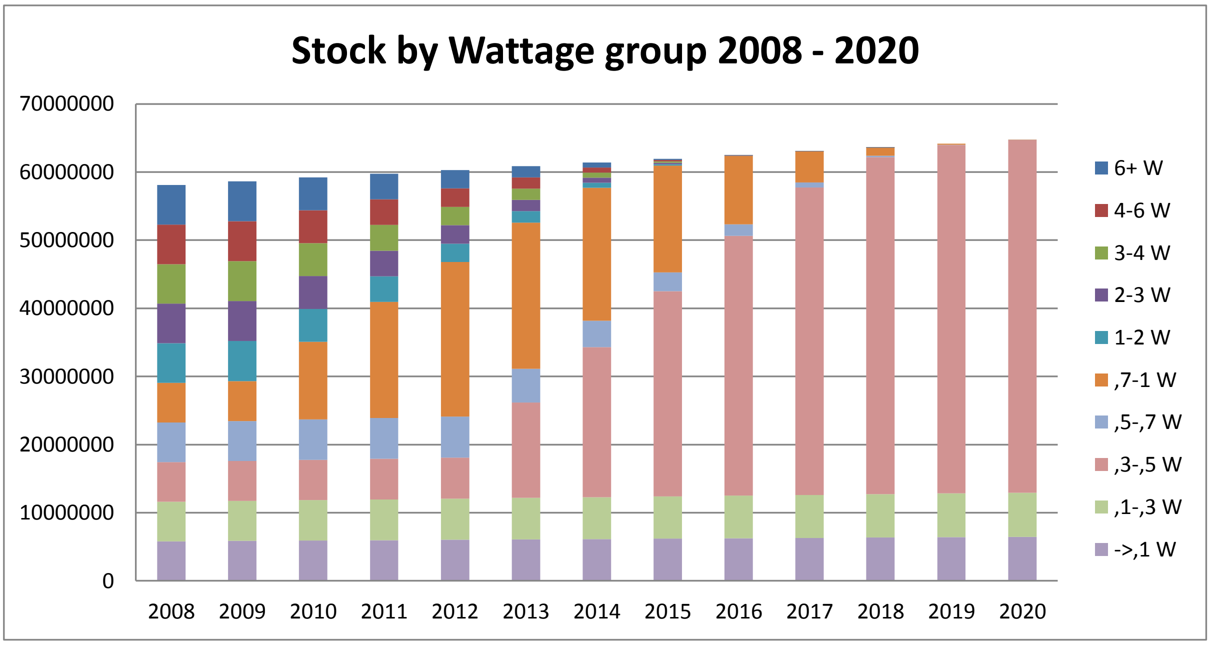
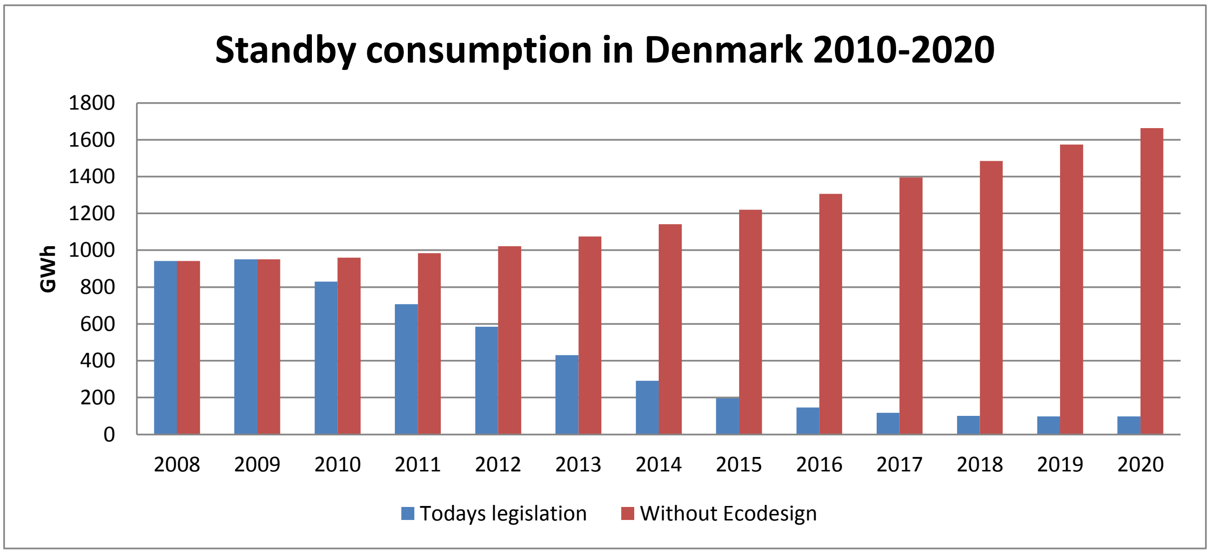


Figure 7. Stock of Standby appliances 2008 - 2020.

This is for scenario 1, where the Ecodesign criterions are applied successively (2010 and 2013) for the annual sales. The stock is fully compliant with the Ecodesign-limit by 2019.

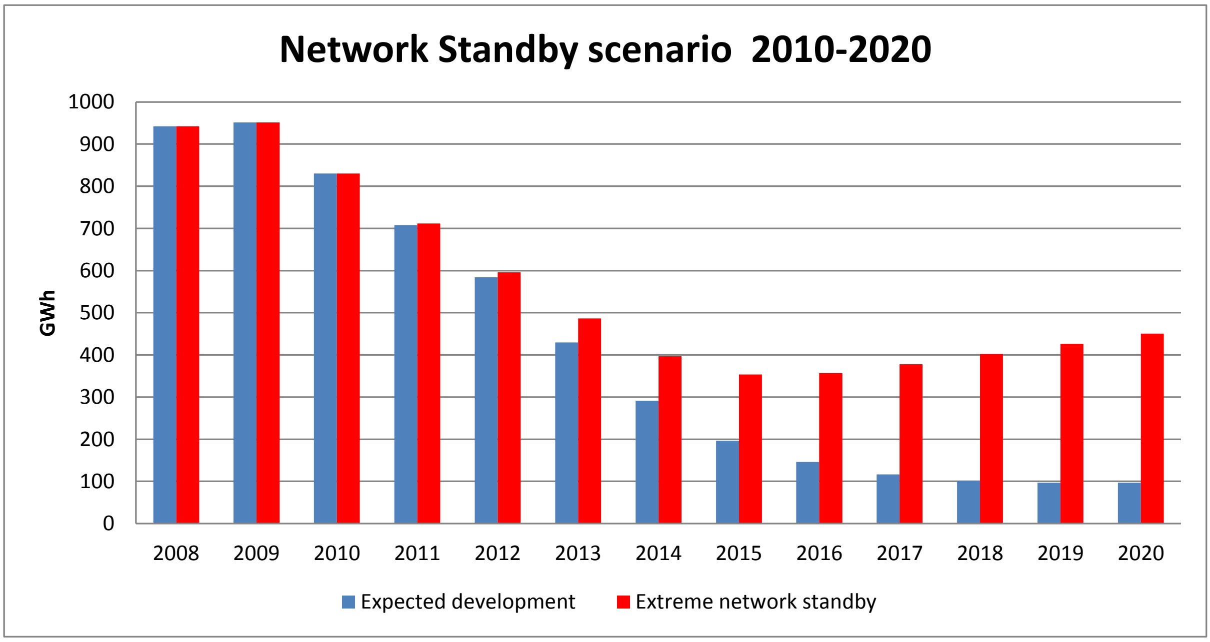
Figure 8. Development of Standby consumption with/without Ecodesign directive.



As seen from figure 8, the estimated impact of the Ecodesign directive is quite substantial. Previously a steady increase in the standby consumption was expected, due to an increase in the ownership levels that overpowered the foreseeable efficiency improvement in most appliance types. Now, a decrease by more than 1,600 GWh is estimated for 2020, even though the standby consumption in the long run still is expected to increase a little, due to the larger stock.

From figure 9 it is clearly seen that Network standby can be a significant threat to the expected success of the Ecodesign directive for Standby. Thus it is extremely important that Lot 26 in the Ecodesign framework on Network standby will produce a rigid limitation of the allowed power for network communication.

Figure 9. Scenario of extreme growth in Network standby compared to standard development.



Findings

This paper provides estimates of standby consumption in Danish homes by 2006, 2008 and 2010, and the possible energy savings from the use of standby killers in Denmark. The estimates are based on various data sources, including ELMODEL-domestic results of the 2006, 2008 and 2010 survey of more than 2,000 Danish homes.

The previous findings for 2006 are:

- Around 16 % of households have at least one standby killer for PC usage
- Around 6% of households have at least one standby killer for TV usage
- Typically each standby killer used with the first PC controls 3,35 additional devices
- On average, each standby killer used with the first TV controls 2,48 devices
- Each standby killer for the first PC saves on average 83 kWh/year.
- Each standby killer for first TV saves on average 58 kWh/year.
- All standby killers with the current ownership levels and usage patterns already saves at least 60 GWh/year in Denmark.
- If all Danish homes used these standby killers, around 456 GWh/year could be saved, corresponding to 4.5 % of household electricity consumption and 1.5 % of all Danish electricity consumption.

Findings for 2010

- Around 26 % of households have at least one standby killer for PC usage
- Around 21% of households have at least one standby killer for TV usage
- Typically each standby killer used with the first PC controls 3,29 additional devices
- On average, each standby killer used with the first TV controls 1,99 devices
- Each standby killer for the first PC saves on average 32 kWh/year.
- Each standby killer for first TV saves on average 17 kWh/year.
- All standby killers with the current ownership levels and usage patterns already saves at least 30 GWh/year in Denmark.
- If all Danish homes used these standby killers, around 152 GWh/year could be saved, corresponding to 1.5 % of household electricity consumption and 0.5 % of all Danish electricity consumption.

For the energy savings given above, they have been weighted by the penetration of the individual devices with regards to the Standby killer. Thus, for printers which are plugged in, in 86 % of the sockets, only 86% of the savings are quoted above, to provide an average across all homes with Standby killers. In homes known to own the appliance, the savings are of course larger.

During the survey questionnaire respondents may not have fully understood the different operating modes. The figures presented here are based on a conservative estimate of standby consumption: i.e. only the lowest power standby mode has been used for estimating savings, though it is likely that some of the usage declared by questionnaire respondents is in a higher/active standby mode.

Final conclusions

Comparing the two sets of findings, it is clear that the effects of Standby killers are slowly vanishing. The ownership levels are higher though, and the plugged in appliances about the same. Only the standby power levels have significantly declined, leading to the conclusion that the sold appliances in 2010, to a large extend are compliant with the Ecodesign directive. The fall in potential savings from 450 to 150 GWh per year, i.e. an already achieved saving of 300 GWh/year, is therefore a significant and promising result we must accredit the Ecodesign directive.

Looking at the scenario for Network standby, the promising result of the Ecodesign directive could easily be corrupted if not the energy consumption in network mode is also addressed in the Ecodesign framework.

References

[1] Standby and Auto power off plug banks, Status for Denmark 2006, IT Energy 2007.

[2] ELMODEL-bolig, Forecast for residential sector 2006, ELMODEL-bolig 2007.

[3] ELMODEL-bolig Data base 2006, ELMODEL-bolig 2007.

[4] Danish Electricity Savings Trust, PR Material 2003/2004.

[5] Technical flaws in TV Auto power off plug banks, not yet published, Technological Institute, 2008.

[6] Electricity Consumption in new vintages of household appliances 1974-2007, ELMODEL-bolig 2008.

[7] SavePower product catalogue 2008.

[8] Field measurements of standby in 100 houses, Lokal Energi A/S, 2004.

[9] The Danish Electricity Saving Trust, www.savingtrust.dk 2008.

[10] A review of the Energy Efficiency Commitment 2005-2008, DEFRA 2008.

[11] ELMODEL-bolig Data base 2004, ELMODEL-bolig 2005.

[12] SELINA, Standby and Off-mode losses in new appliances measured in shops. IEE 2010.

[13] ELMODEL-bolig questionnaire results 2008.

[14] ELMODEL-bolig questionnaire results 2010.

[15] “AutoPowerOffPlug banks – a success story”, Jensen et al., paper no. 4115, ECEEE 2009.

Market Trends on the TV Market and their Impact on Energy Consumption

Thilo Heyder

GfK Retail and Technology GmbH

1. Abstract

To specify the efforts for climate protection the administration of the European Union is now adopting

> "measures for products which have a significant potential for saving energy, and where relevant, other resources, and a wide disparity of relevant performance levels for equivalent functionality"[1].

Within this context TVs are identified as relevant devices having a significant environmental impact related mainly to the electricity consumption in the use phase (cf., Commission Delegated Regulation, 28.09.2010). Therefore an energy label for TV sets has been introduced - defined and available since the end of 2010 - mandatory from November 2011.

A deeper insight into the European TV market[2] will help to understand future challenges by analysing current market trends and their impact on energy consumption. It will become obvious that we are facing a multidimensional issue that demands a continuous and precise evaluation.

2. Introduction

When analysing the relevant factors that impact the development of TV related energy consumption we have to differentiate between

- usage / consumer related patterns (TV viewing time, multi ownership / number of TV per household) and
- product / technology related characteristics (energy consumption per device).

Whereas the former is comparatively hard to influence by top down decisions, the latter is much more capable to adjust the energy consumption effectively.

So when we first look at TV related usage patterns, it is to show and make clear the relevance of pushing forward the technological development towards energy efficient devices. Secondly, it is necessary to understand the market dynamics and their impact on the energy consumption related issue. In consequence we will see that a continuous market observation is necessary to keep up with an ever-changing TV market, enabling an adaptive control equipment that fits with each of the status quo.

2.1 Methodological annotation

[1] COMMISSION DELEGATED REGULATION (EU) No …/.. of 28.9.2010, supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of televisions, p.2.

[2] If nothing different is mentioned, all data related to TV mentioned hereafter are basing on market sales out data audited within the retail panel by GfK Retail and Technology in 15 selected European countries, these are: DE, FR, GB, IT, NL, ES, AU, BE, SE, CH, DK, FI, IE, GR, PT.

All figures regarding sales volume or market share mentioned below are based on the international GfK Retail and Technology retail panel. Data from this retail panel show retail sales out information including volume, value, price, feature sets etc. for defined product groups down to single item level. Statements regarding energy consumption in Watt are based on the information published by the manufacturers. The calculation of energy consumption in kWh is based on an on-mode time of 4 hours per day plus 20 hours standby. With the introduction of the new label GfK will base energy consumption related records and calculation on the information given on the label.

3. Increasing average TV usage time exacerbates the challenge

Within the recent past the usage of TV has been intensified, i.e. we are facing an increasing on-mode-time. Several indicators corroborate this thesis.

3.1 Increasing TV viewing time

From year 2007 to 2009 the average time spent watching TV increased constantly. Focusing only on usage for content provided by broadcasters in year 2009 the Europeans run the TV 3.85 hours a day.

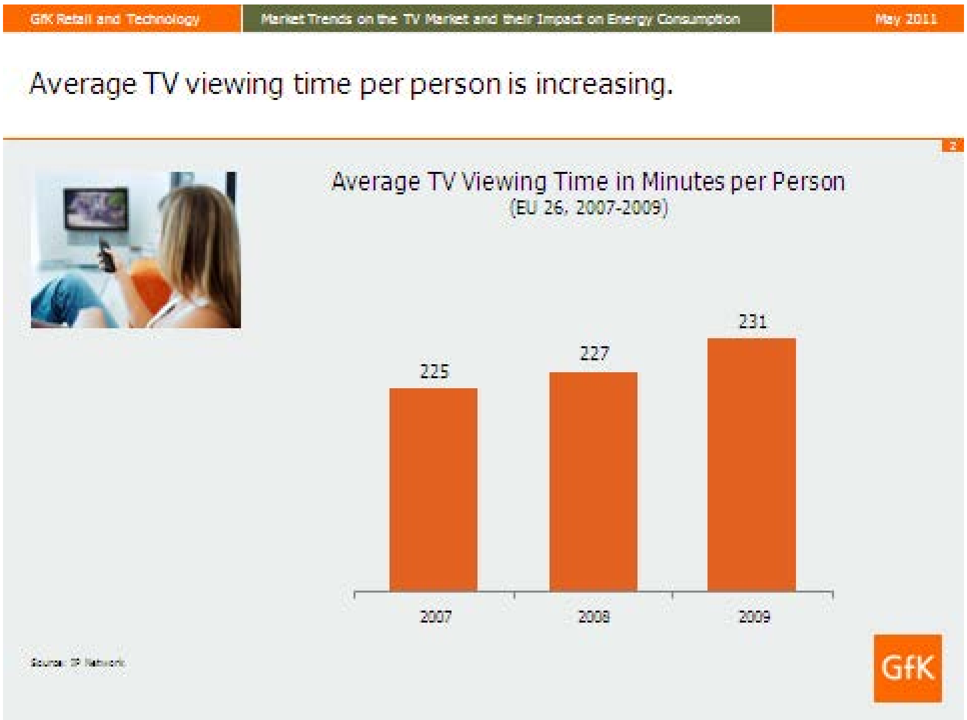


Figure 1: Source: IP Network

3.2 Increasing number of devices to be used directly connected to a TV

Television usage cannot be reduced on watching broadcasted content as there are several devices that typically have to be used in combination with a TV, e.g. DVD / Blu-ray player / recorder, external hard disc drives and video games consoles.

Although we see a declining market for DVD / Blu-ray player / recorder, it is the total number of devices sold that gives an idea of the market penetration and therefore the relevance of this product group in regard to on-mode time of TV. From 2006-2010 about 125 Million DVD / Blu-ray player / recorder have been sold in Europe.

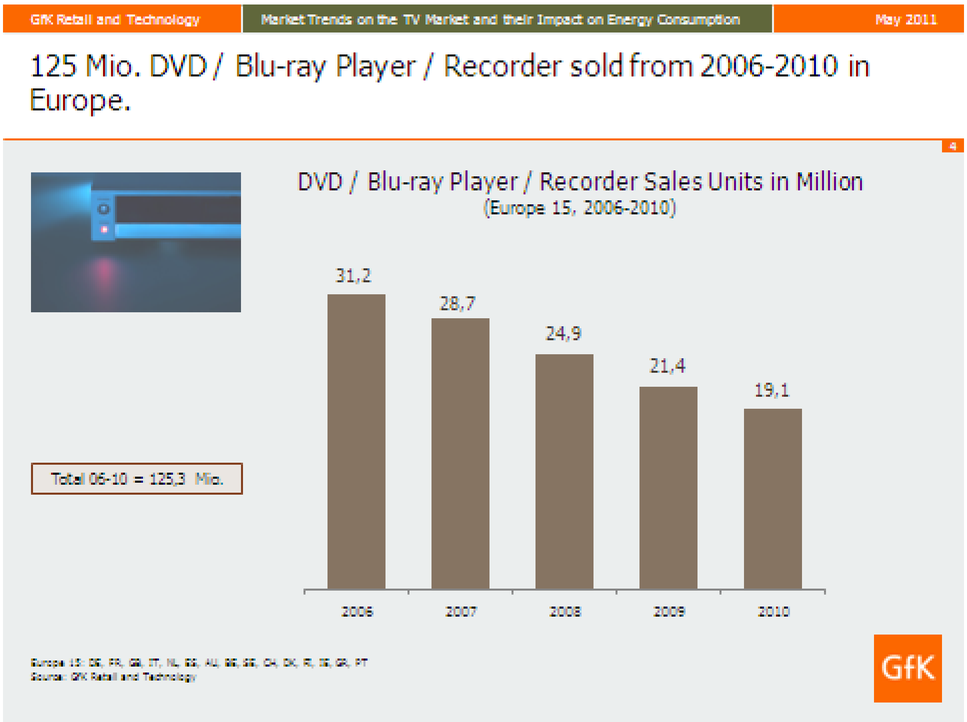


Figure 2: Source: GfK Retail and Technology

Another product group influencing the on-mode time of TVs are video consoles. In the recent past video consoles became more and more popular, especially driven by a qualitative shift towards more interactivity of the games available now not only addressing children or teenager but also adults. So within the last five years nearly 110 Million consoles have been sold.

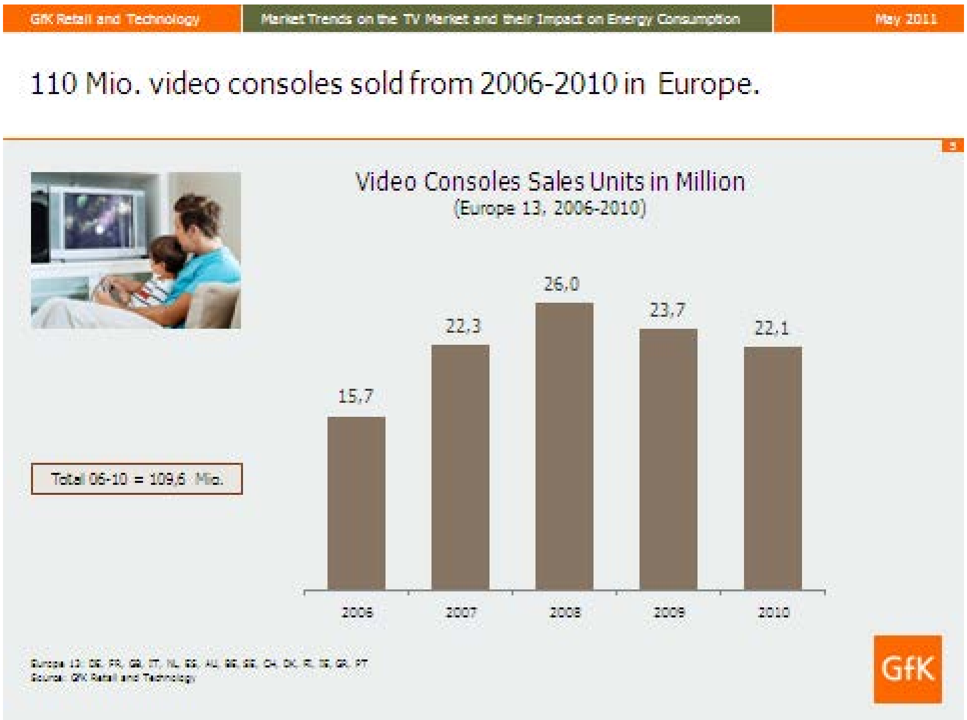


Figure 3: Source: GfK Retail and Technology

Both viewing time and combined usage indicate an increasing on-mode time for TV sets – i.e. increasing energy consumption – and there are neither any signals that this trend will turn around within the near future nor a chance to regulate by legislation.

Thus a four hour on-mode time per day which currently is the basis for calculating the energy consumption in kWh per year shown on the new energy label for TV might be further discussed.

3.3 Increasing number of TV

Looking at the TV related energy consumption per household another important indicator is changing continuously - number of TV sets in use. Even by only assuming a five year product life cycle there are more than 213 Million devices in use across Europe 15 basing on the sales out data of the international GfK retail panel from 2006-2010. With an average year to year growth rate of about 10% within the last 5 years the TV market is subject to a constant positive dynamic.

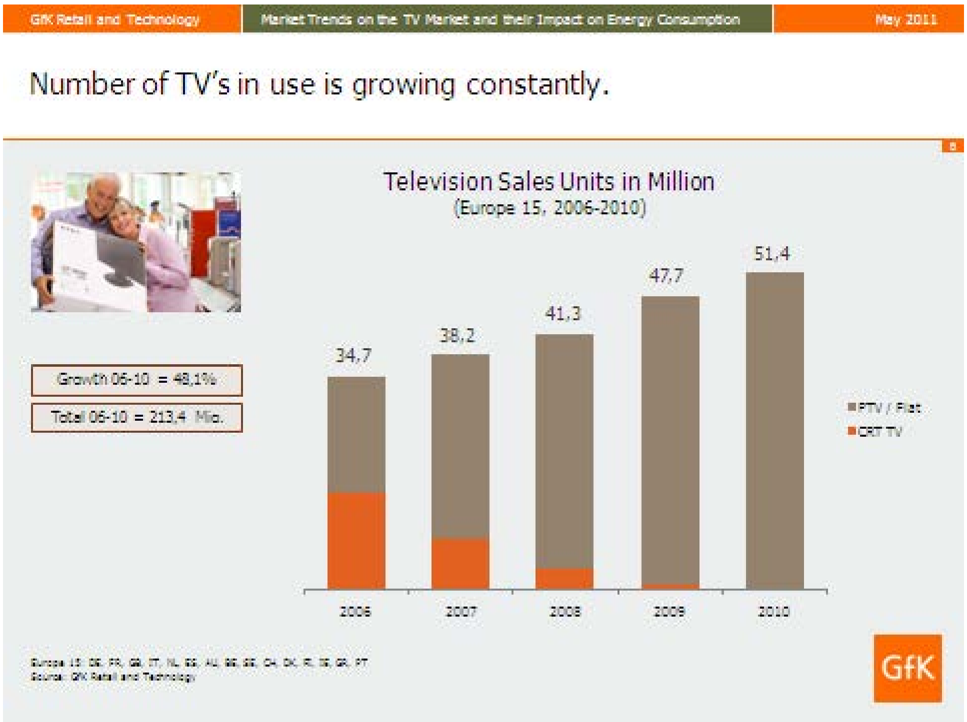


Figure 4: Source: GfK Retail and Technology

The growing number of TVs in use does not only again underscore why a consequent regulation of TV related energy consumption makes sense but also that we have to monitor the market regularly to understand the efficiency of these measures – and to adapt them if necessary.

4. Market trends and product development

The growing number of TV sold and therefore of TV in use immediately raises the question about the impact of this development on energy consumption. To analyse this issue more detailed we will gate out CRT TV and focus on Flat TV. Pushed by the new form factor the Flat TV market had been growing rapidly in the recent past and has now almost completely displaced CRT TV.

4.1 Improvements in energy efficiency become effective

Looking closer at the development of energy consumption it can be seen that improvements are already in progress. As the energy demand of Flat TV sets especially was increasing at the beginning of the “Flat-era” since 2009 a significant reduction can be recognized. Thus although the number of TV sold from 2009 to 2010 was increasing the total energy usage of this TV sets could be reduced. This was achieved by a reduction of the average energy consumption per TV set by 16.3% from 141 Watt to 118 Watt or 206 kWh/year to 173 kWh/year.

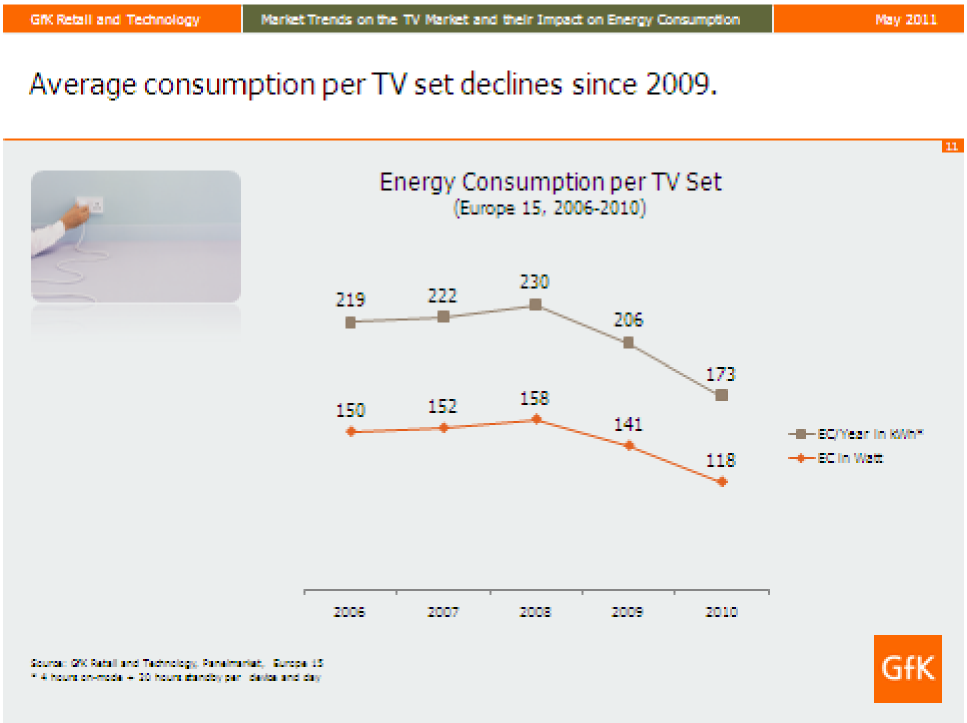


Figure 5: Source: GfK Retail and Technology, manufacturer’s data

Quite remarkable when considering that the trend is not only towards more TV sets sold but also towards bigger screen sizes. Thus in Europe 15 the share of TV sets featuring a screen size of 40 inch or more increased from 17% in 2006 to 27% in 2010. Considering that we are looking at a constantly growing market the growth for the 40+ inch segment in absolute numbers is even more impressive.

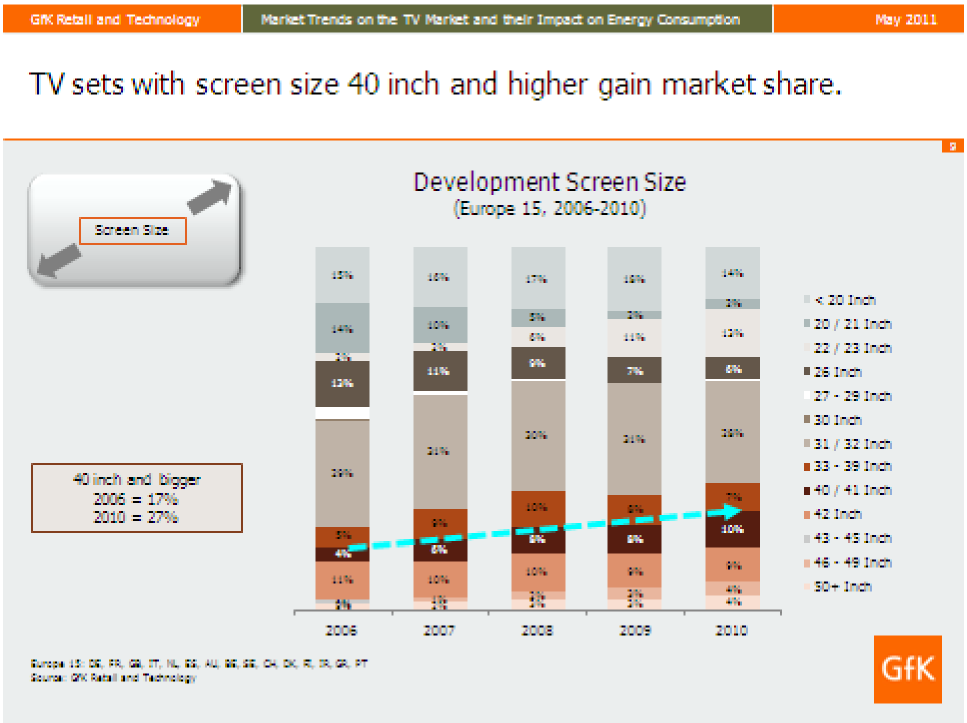


Figure 6: Source: GfK Retail and Technology

Knowing this, it becomes obvious that an improvement of the energy efficiency of bigger TV sets with bigger screen sizes is of high relevance. When comparing the inch size classes with one another a reduction of energy consumption can be found for all relevant inch size classes. Nevertheless it has to be taken into account that even if the energy consumption in each size class could be reduced there is a significant inter-size difference and therefore the trend toward higher screen sizes is one of the major challenges. So in 2010 the average on-mode energy consumption of a 22 inch Flat TV was 54 Watt whereas it was 137 Watt for a 40 inch TV set.

	Average Energy Consumption in Watt				
	2006	**2007**	**2008**	**2009**	**2010**
up to 20 Inch	49	50	53	50	45
20 / 21 Inch	64	61	56	54	49
22 / 23 Inch	92	83	66	61	54
26 Inch	112	113	110	99	80
27 - 29 Inch	134	117	126	98	69
30 Inch	161	177	171	160	160
31 / 32 Inch	145	144	147	136	116
33 - 39 Inch	196	187	181	163	141
40 / 41 Inch	215	200	203	179	137
42 Inch	289	275	268	232	194
43 - 45 Inch	276	249	232	279	266
46 - 49 Inch	253	261	268	237	181
50+ Inch	321	385	409	339	269

Table 1: Source: GfK Retail and Technology, manufacturer's data

4.2 Potential for improvement still not exhausted

Considering the growing sales out numbers and the tendency towards bigger screen sizes, it has to be stated that the improvement of energy efficiency achieved so far is not enough especially against the background of the goals regarding the reduction of TV related energy consumption as mentioned in the respective Commission Regulation[3].

But when going into detail within a specific screen size class a significant range of energy consumption values can be seen making clear that there still is potential for improvement. To point out the inter-model deviation, it makes sense to focus on a specific example shown on the table below[4]. As this example shows the energy consumption between two models can differ significantly even if both are featuring a similar set of product characteristics.

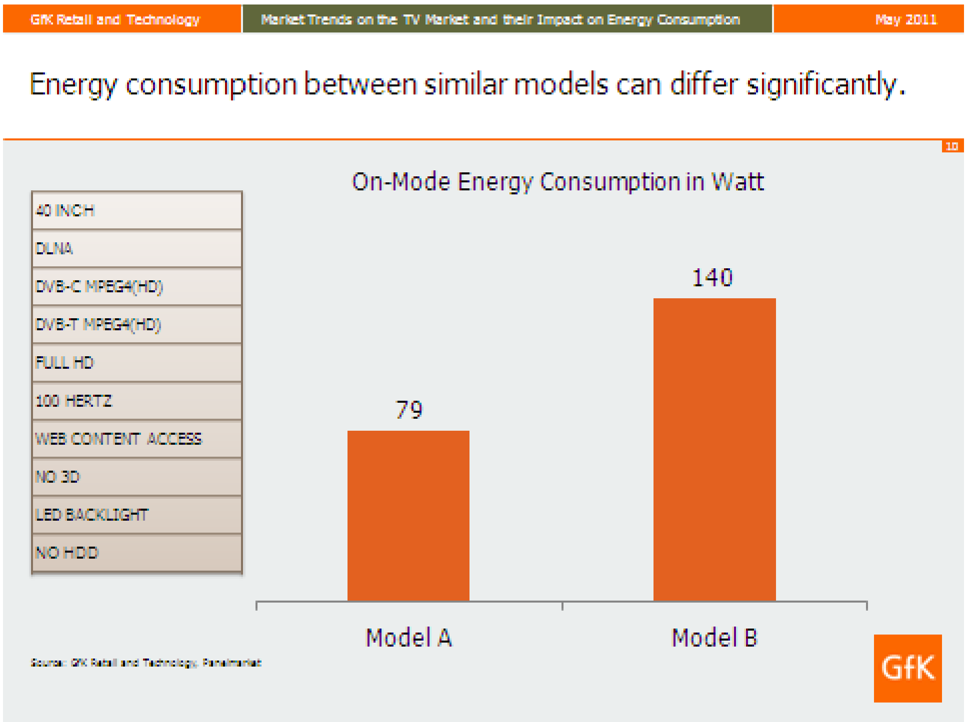


Figure 7: Source: GfK Retail and Technology, manufacturer's data

As this example shows, the implementation of energy saving functionalities is able to reduce the energy demand significantly. Nevertheless this technological innovation becomes only effective when it is directly linked to the sales out development and thus impacts the total energy consumption of TV sets in use.

5. The new energy label for TV and it's implications

The European Commission introduced an energy label for TV sets, available since the end of 2010 and becoming mandatory from December 2011. The label shows relevant energy consumption facts and a classification of the regarding device with a range from A (lower consumption) to G (higher consumption). The ultimate objective is to push the market penetration of energy efficient devices and thus supporting the efforts made to reduce CO_2 emissions.

---

[3] Commission Regulation (EC) No 642/2009 of 22 July 2009

[4] Both models are from hitlist (top 100 by sales units), Germany, Jan.10-Nov10

Keeping this in mind the following questions need to be answered:

- Is the energy label really pushing the sales volume of energy efficient devices?
- If there will be a trend towards energy efficient devices, is it able to compensate the effects caused by increasing the number of TV sets sold and the tendency towards bigger screen sizes?
- Will we really see a decline of the fleet consumption in the near future?
- Will we see country specific developments showing different paces of market transformation?

For answering this question it is necessary to continuously monitor the TV market development on a European and also country wise level. This will enable us to get in touch with each of the status quo and to adopt the measures implemented now if necessary.

6. Consumers purchase behaviour will be affected due to the energy label

With the establishment of the energy label the consumers purchase decision will be driven more by concerns regarding energy consumption than it has been in the past. And indeed consumers are not only able to have a stake in saving the environment but to benefit economically from deciding for an energy efficient device. Assuming a life cycle of seven years with an on time of 4 hours per day the average share of energy costs in Germany for a TV set featuring a 42 inch screen size is about 30% - and this can be assumed to be similar in other European countries. Depending on the specific model this share can of course be even bigger.

Looking on energy consumption related costs it becomes obvious that there is a significant difference not only between different screen size classes but also between different manufacturers and models within a screen size class. Therefore consumers cannot only save money when deciding for an energy efficient device but more than this basing on the total life cycle costs for some TV models lower energy costs make possible to compensate higher purchase price as shown by a GfK market analysis for the Top 10 selling models 42 inch Flat TV in Germany in December 2010.

Easy to understand that this argument will have a strong impact on the purchase decision and that the transparency of energy related information as provided by the energy label will push the TV market going green.

An evaluation of standby losses effect in power demand in Greek urban households

C. S. Psomopoulos, TEI Piraeus, Dept. of Electrical Engineering

G. C. Ioannidis, TEI Piraeus, Dept. of Electrical Engineering

S. Tsiolis, TEI Piraeus, Dept. of Electrical Engineering

M. Lagiou, TEI Piraeus, Dept. of Electrical Engineering

Abstract

Standby consumption is a global phenomenon because the largest "leakers" are internationally-traded appliances usually line-powered electronic equipment (office equipment, televisions, audio equipment, illumination electronics, home entertainment devices, communication devices, consumer appliances, etc.). Usually, these electronic devices are permanently connected to the low voltage network through a plug. The standby power consumption of one device could be neglected, but if the number of the above mentioned devices connected at the same time in a network is high, then this consumption could be high enough to affect the power demand. Currently, it represents 5-11% (depending on the region and related estimations) of the total electricity demand in European households, mostly concentrated in entertainment and office equipments. This paper is focused on the evaluation of the standby losses in typical urban areas of Greece. Detailed power consumption measurements in twenty homes located in different areas of Athens - Greece are presented and analysed. Moreover, an analytical survey concerning the type and the quantity of electric/electronic devices used by a considerable number of families is also presented. Furthermore, recent and old detailed power consumption measurements, of the most common modes of operation (on, off and standby), in other member states of Europe are presented and analysed giving the opportunity to compare the situation in a typical urban Greek area and the respective in other parts of Europe. The presented data reveal the magnitude of the standby losses problem in Greece and the potential benefits gained by the enforcement of recent EU policies.

Introduction

In recent years, the increase in energy consumption from appliances not being used for their primary purpose (or in “standby” mode) has become a major concern [1, 2, 3]. Even though this energy consumption could be easily considered negligible for a single device; when the millions of appliances installed around world are considered, and the fact that this energy is consumed continuously, the energy consumption is not negligible. Currently, it represents 5-11% (depending on the region and related estimations) of the total electricity demand in European households (excluding electric space heating and electric hot water preparation), mostly concentrated in entertainment and office equipments [4, 5, 6, 7, 8]; studies from other parts of the world tend to show similar results [3, 9-21].

EU through the EcoDesign Directive have launched studies (LOT 6, LOT 26) in order to determine the magnitude of these losses as well as the reduction potential and the related policies to determine especially these losses, in the framework of this Directive. In December 2008, the EU Commission adopted the Commission Regulation (EC) No 1275/2008 referring to standby and off-mode electric power consumption, targeting to a reduction of 35TWh in 2020.

The term “standby losses” describes better the presented situation because of the electricity consumption of electronic devices while “off” or in a powered down state, and nowadays, is the most accepted as these electric loads have been labeled in literature as “vampire”, parasitic or simply leaking electricity. The term “standby”, as it is defined in literature, is based on basic operating conditions and refers to the following three major categories: [2, 4, 7, 8, 21, 22]

- Off. When a product or appliance is connected to a power source but does not produce any sound or picture, transmit or receive information or is waiting to be switched “on” by the consumer. If the product has a remote control, it cannot be woken by the remote control from off mode. While the product may be doing some internal functions in off mode (e.g. memory functions, EMC filters) these are not obvious to the user.

- Passive Standby. When a product or appliance is not performing its main function but is ready to be switched on (in most cases with a remote control) or is performing some secondary function (e.g. has a display or clock). This mode also applies to power supplies for battery operated equipment (portable appliances which are intended to be used when disconnected from the base station) when the appliance is not being charged.

- Active Standby. Active standby is mostly applicable to DVDs, VCRs and some stereo equipment where operation involves some mechanical drive (DVD and CD players). Active standby is the state at which the appliance is on but not performing its main function. For example, the DVD may be on but is not playing or recording. This mode also applies to power supplies for battery operated equipment (portable appliances) when the appliance is being charged (various sub-modes).

Typically, standby losses occur in different condition or “services” provided to the user. In such functions the device is waiting to be turned on and requires power either to be able to respond to a signal (e.g. remote control), to maintain an environment beneficial to the user (memory) or to speed up the device’s response to an on signal. Other functions, such as clocks on microwaves and DVDs, offer a legitimate service to the user, although it is not the primary function of the device. Other loads are pure losses and offer no service to the user. Standby also includes electrical power consumed by appliances that use other fuels as their primary energy source (e.g. gas water heaters or space heaters).

Household standby consumption was the subject of many surveys and measurements in the last decade. The best of them have been used by European Union, USA DOE, Japan, Canada and International Energy Agency (IEA), in order to evaluate the standby losses and to determine the potential for reducing them [1-14, 16-27].

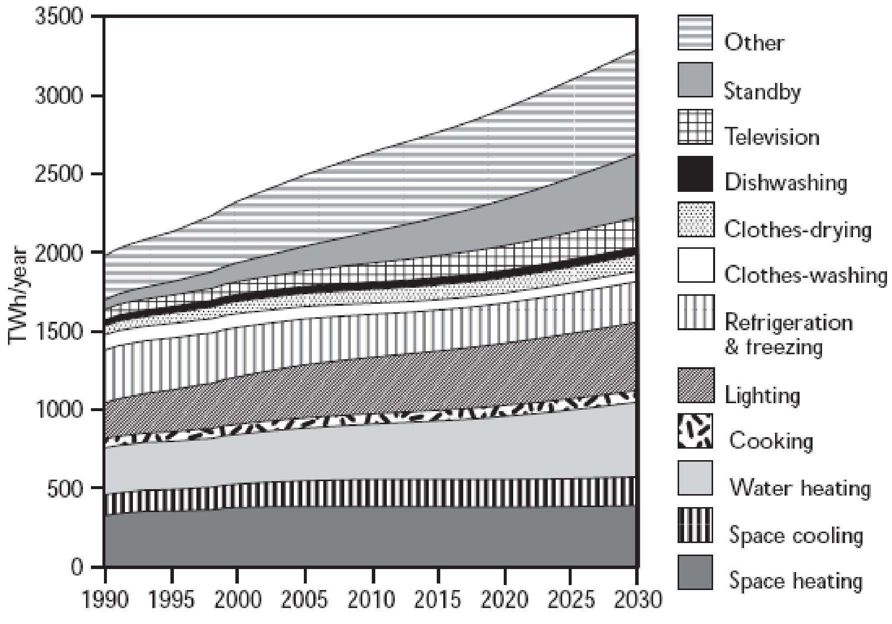


Figure 1: Projected IEA residential electricity consumption by end-use with current policies [22]

The fact that energy labels and a few Minimum Energy Performance Standards have been introduced in the EU, in the last fifteen years, has increased the sales of more energy efficient appliances. On the other hand, the number of electrical and electronic loads which are connected to the AC supply, typically all the time, has also increased. The IEA estimated that, even with a continuation of all existing appliance policy measures, the appliance electricity consumption will grow by 25% from 2000 to 2020 [22].

From Figure 1 is evident that the fastest growing electricity demand is projected to be standby/off-mode power consumption. That is the electricity consumption by appliances that are turned “off” or, that are in a low power consumption mode.

According to IEA, by 2030 Europe could be due to standby functionality. This also represents the largest potential saving, as measures to reduce standby consumption have just begun.

This paper is focused on the evaluation of the standby losses in typical urban areas of Greece. Detailed power consumption measurements in twenty homes located in different areas of Athens - Greece are presented and analysed. Moreover, an analytical survey concerning the type and the quantity of electric/electronic devices used by a considerable number of families is also presented. This study was carried out for a bachelor thesis in the Department of Electrical Engineering of the Technological Education Institution (TEI) of Piraeus. Furthermore, recent and old detailed power consumption measurements, of the most common modes of operation (on, off and standby), in other member states of Europe are presented and analysed giving the opportunity to compare the situation in a typical urban Greek area and the respective in other parts of Europe. The corresponding data come mainly from the European project SELINA ([29]). The presented data reveal the magnitude of the standby losses problem in Greece and the potential benefits gained by the enforcement of recent EU policies.

Quantification Methods Used

The methods used for quantifying the standby consumption in typical houses located in Greek urban areas involved product measurements and bottom-up estimates. The measurements performed using a power meter SEM16+ (Figure 2) which measures one phase loads up to 230V/ 16A. The SEM16+ is a measuring device to determine the electrical energy consumption costs for individual electrical one phase up to 16A equipment in households. The SEM 16+ starts automatically a 24h measuring period after the unit to be tested has been plugged in. After completion of the measuring period the energy consumption and the energy costs for the period will be displayed. The period of the measuring can be changed to 1, 7 or 30 days and manually started and stopped. During and after completion of measuring the results of power, costs per year, energy consumption, costs and equivalent CO_2 consumption at the measuring period, voltage, frequency, current, idle power, apparent power, phase shift, power factor, minimum and maximum power can be called. Table 1 shows the main technical characteristics of the power meter used. The bottom-up estimates are based on the type and number of devices used in 20 typical houses in urban areas of Greece. The average home’s standby power use would be calculated from a combination of field measurements, like the ones mentioned above and known appliance saturations. Based on the questionnaires used on the survey and measurements results an estimation of the standby power consumption per house is attempted. These results are used further to evaluate the magnitude of the standby power consumption in residential sector in Greece and by this the contribution in the annual electricity consumption of the country.

Following the measurements execution, a survey in 200 typical families – households about their green procurement behavior and the criteria that the consumers have in their choices in domestic appliances selection and usage is conducted. In these 200 families – households participated in the survey; the 20 households (in which the previous mentioned measurements were performed) were included. The people were asked about their education level, ages, type of equipment in use, criteria usually used for selecting the domestic appliances, settings used in cooling and heating devices, etc. A questionnaire was prepared for the purposes of the survey and several copies were distributed through students and Professors of the Electrical Engineering Department of the Technical Educational Institute of Piraeus. The students were randomly selected and most of them provided questionnaires from households of their close relatives or friends as well. At the ending of this procedure 200 questionnaires were collected and evaluated. The measurements and survey's results are presented in the next section.

Figure 2. Power meter SEM 16+

Table 1. Technical characteristics of the used power meter SEM 16+

Technical characteristics	
Input voltage:	230 VAC ±10%, 50/60 Hz
Max. load:	16A, 3680 VAr
Measuring Range	0,1 – 3680 W
Precision	1%; ±1 Digit
Protection Class	IP20

Results and Discussion

As it was mentioned in the previous section, the 200 collected questionnaires are analysed and the results are presented in the following Figures. Figure 3 shows that the majority of the users (68%) which participated in the survey are between 18 and 25 years old, and 25% of them are between 25 and 35 years old. Moreover, the majority of the participants have university education (54%) and a 27% of them have technical vocational education.

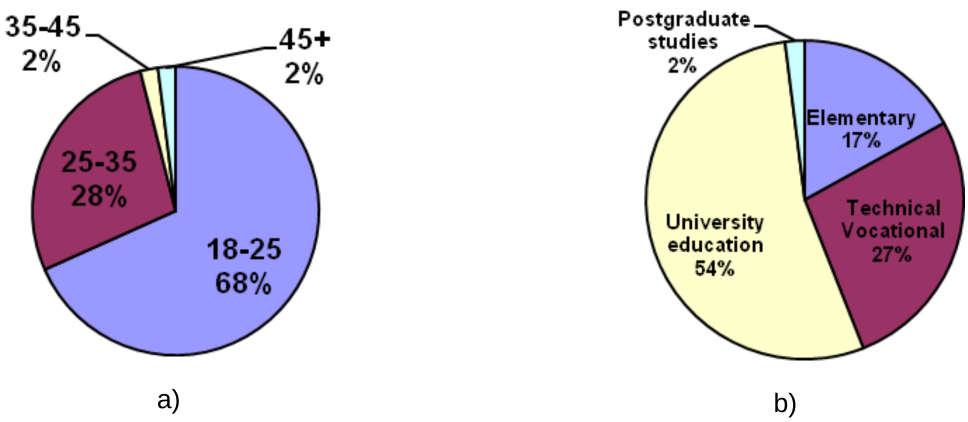
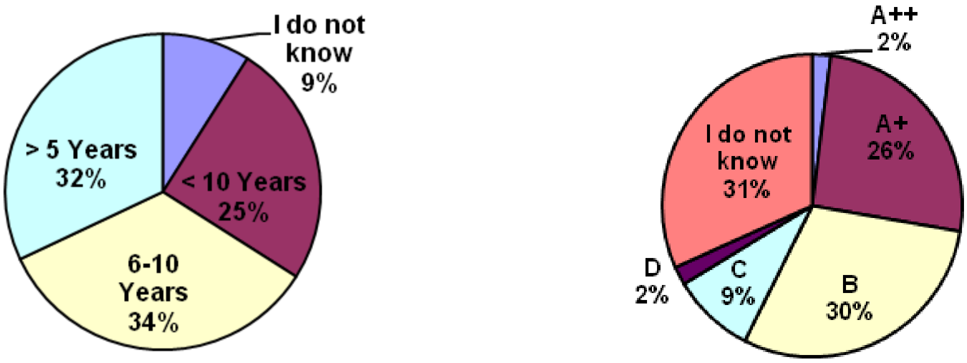


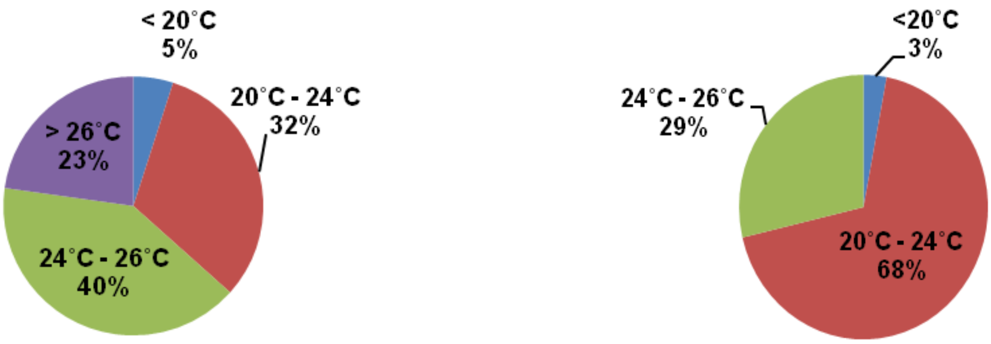
Figure 3. a) Age of users b) Education level of the users

In Figure 4 the age-related distribution of the appliances which the participants possess, is presented. Most of the appliances are 6-10 years old and a 25% of them are less than 5 years old. Furthermore, 30% of the appliances are B class and 26% are A+ class. Also, the habits of the questionnaires on the temperature setting during heating and cooling period were recorded and presented in Figure 5. It is evident that both during heating and cooling periods the temperature setting was higher (heating) and lower (cooling) compared to those which correspond to the conditions of comfort and economy (20^0C and 26^0C during heating and cooling periods respectively).



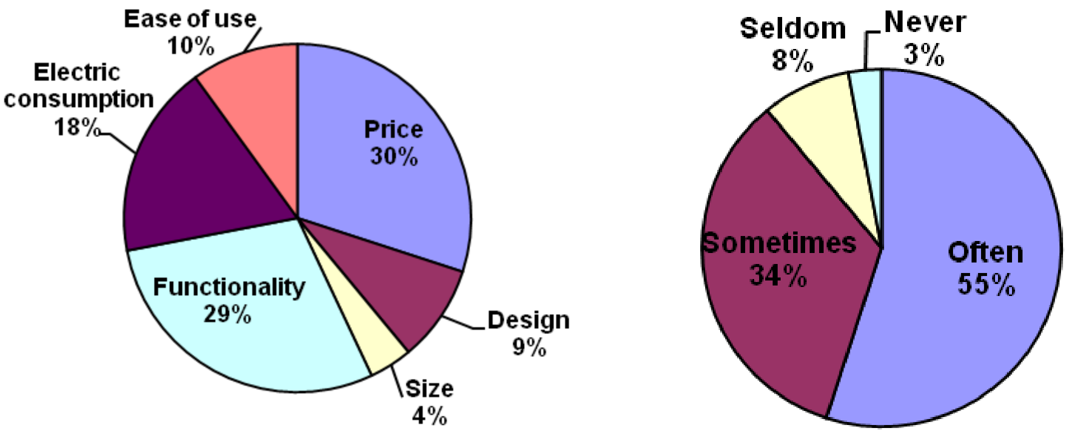
a) b)

Figure 4. a) Age – related distribution of home appliances b) Energy label of home appliances



a) b)

Figure 5. Temperature setting of internal spaces during a) heating and b) cooling seasons



a) b)

Figure 6. a) Criteria of purchase of new home appliances b) frequency of replacing conventional bulbs with economic ones

In Figure 6a the criteria of purchase of new home appliances are presented for the participants in the survey. As it can been shown the most important criterion is the price (30% of the questionnaires) then the functionality of the device (29%) and only 18% of the questionnaires purchase appliances based on their electric consumption.

Furthermore, as far as it concerns the replacement of conventional bulbs with economic ones, the users seem to have to trouble to do so (55% often and 34% sometimes) as it is seen by Figure 6b.

As it was mentioned in the previous section, standby measurements have been conducted for 20 households inside the urban section of Athens and the results can be shown in Figure 7. As it can be seen from this Figure, stereos and printers present the highest standby consumption. Also, appliances like set-top boxes and LCD TVs have low standby losses. These appliances have been widely used the last 2 to 4 years in Greek homes and are basically new technology devices in which manufacturers have implemented low energy consumption modules, conforming to the requirements of latest European standards.

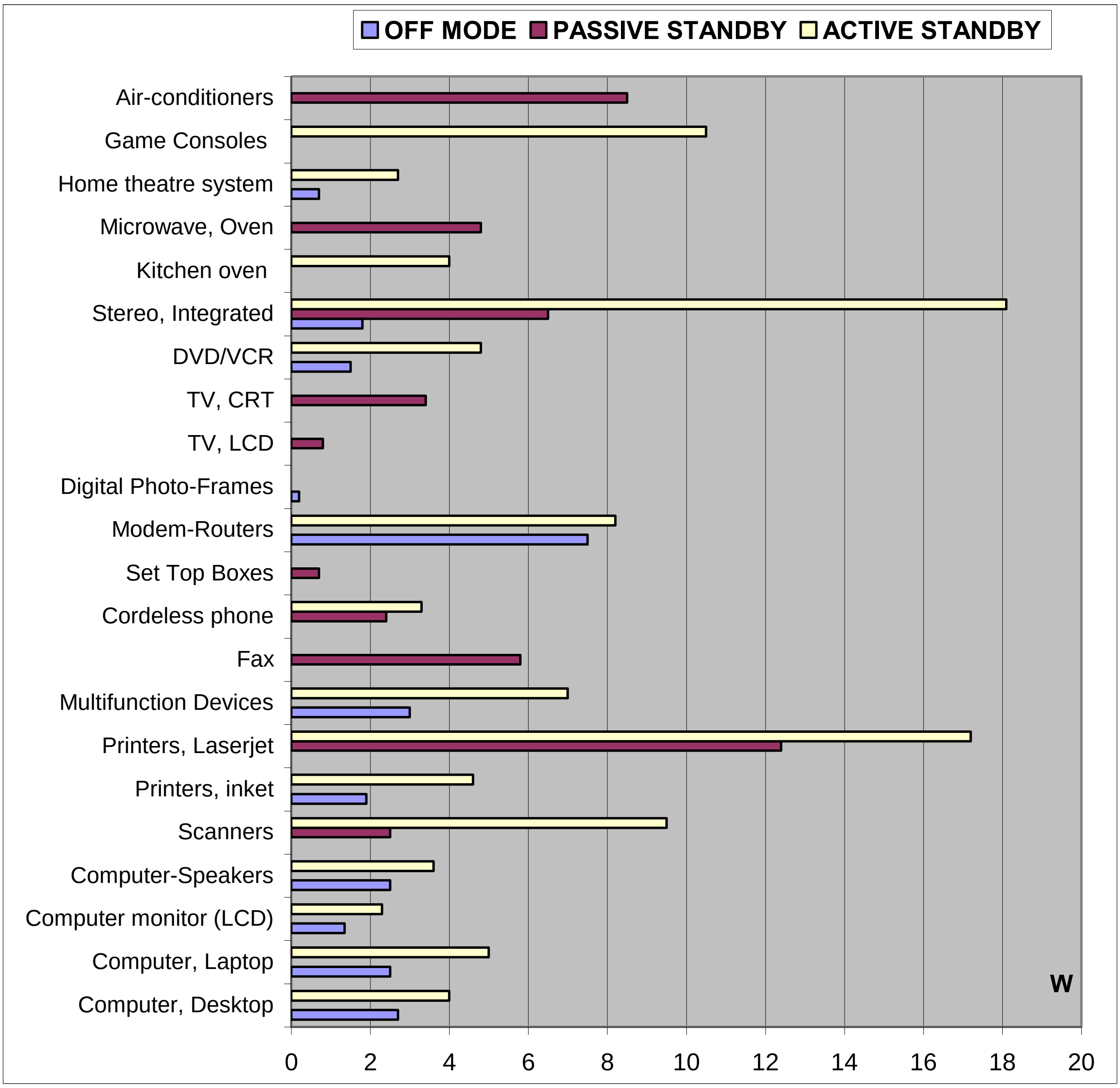


Figure 7. Off mode, passive standby and active standby measurements

Furthermore, the weighted measurement of the total standby consumption of an average home has been estimated and is about 76.34W. According to reference [6], the average electricity consumption for a typical Greek household is 4670kWh/year. Taking into account an increase of 10% of energy consumption over the five years that have passed since the publication of the results of reference [6], the average electricity consumption per household is estimated to be 5137kWh/year. This energy consumption corresponds to an average power consumption of about 586W. Therefore, the average standby consumption of an average Greek home corresponds to about 13% of the respective total average power consumption. These results seem to be in accordance with the findings of other studies. In particular the existing studies for estimating the standby consumption are focus on household appliances and mainly in electronic appliances. Up to now, several estimations for the contribution of the standby consumption in residential have been produced, indicating the magnitude of the losses. Studies in Germany, Denmark, the Netherlands, and the US have found that standby power accounts for as much as 10% of national residential electricity use [1-8, 11, 16, 21]. Estimations of standby power consumption in the European Union (EU), as it is already mentioned before, showed that it corresponds up to 11% of total residential electricity consumption [1, 3-8]. Case studies of individual homes have been reported for houses in Sweden, France, UK, Japan, the US, China, Argentina, South Africa and New Zealand [6, 10, 11-14, 17-20, 24]. Standby power ranged from 70 to 125 W, but even though the examined homes were similar to the representative ones in each country, in some cases this important parameter couldn't be retained. In Japan, the Energy Conservation Centre (ECCJ) estimated that the standby consumption was 308 kWh/year or 7.3% of the power consumption of a whole house [24-26]. A very detailed study in Australia showed that the household standby power consumption averaged 87 W, and energy consumption averaged 760 kWh/year or 11.6 % of the household total energy consumption [9, 10, 27]. The relatively low standby power loss values which were found in Greece compared to other parts of Europe and elsewhere in the world is justified by the fact that the penetration of internet and other communication and audiovisual services in Greece is among the smallest in EU in the domestic sector.

Table 2. Measurements of the standby and off mode power demand in household appliances

Standby and off-mode power consumption in [W]					
	Unit	**Number of Devices**	**OFF MODE Average**	**PASSIVE STANDBY Average**	**ACTIVE STANDBY Average**
1	Computer, Desktop	12	2.7		4
2	Computer, Laptop	4	2.5		5
3	Computer monitor (LCD)	12	1.35		2.3
4	Computer-Speakers	8	2.5		3.6
5	Scanners	4		2.5	9.5
6	Printers, inkjet	5	1.9		4.6
7	Printers, LaserJet	4	0	12.4	17.2
8	Multifunction Devices	7	3		7
9	Fax	3		5.8	
10	Cordless phone	14		2.4	3.3
11	Set Top Boxes	10		0.7	
12	Modem-Routers	16	7.5		8.2
13	Digital Photo-Frames	5	0.2		
14	TV, LCD	30		0.8	
15	TV, CRT	2	0	3.4	
16	DVD/VCR	20	1.5		4.8
17	Stereo, Integrated	19	1.8	6.5	18.1
18	Kitchen oven	20			4
19	Microwave, Oven	15		4.8	
20	Home theatre system	3	0.7		2.7
21	Game Consoles	8	0		10.5
22	Air-conditioners	36		8.5	

In other words the results, in Greece, are presumable because the number of the electronic equipment required for these services are low, Based on previous, it is expected that the standby consumption in the Greek domestic sector will be rather increased but not much because of the legislation that is getting more and stricter. This could be explained by the fact that these devices usually came to Greek market with a delay of one to two years, and thus the producers have already comply with the legislation requirements.

As it can be seen from the measurements presented in table 2, the domestic appliances used in Greece are presenting low power consumption in standby “off mode” and “passive mode”. In some cases (home theatre, digital photo-frames) the consumption is very low, below 1W, while in others the results are not that low. If these results are compared with the ones presented in Table 3 the similarities can be easily revealed.

Table 3 presents measurements performed in new equipment produced under the most recent EU studies about standby consumption and as it can be seen the results are similar to the ones measured in Greek urban areas. The similarity can be easily ascribed to the fact that in the Greek market the equipment is appeared with a delay of 1-2 years. This delay of entering the appliances into the market is responsible for the better characteristics of them and consequently, lower standby consumption. Furthermore, considering the consuming characteristics of the users it can also be seen that one important parameter is the energy consumption as well as the price of a domestic appliance. Based on these facts, it is obvious that the equipment which is bought and in use, in the average representative Greek home, is usually in accordance with the newer standards.

Table 3: Power demand at “off mode” and “passive mode” as it was measured during the SELINA Project [29]

Power Consumption in Watts (W)	"OFF MODE" Average	"PASSIVE MODE" Average
Computer-Laptop	0.5	0.85
Computer monitor	0.5	1.97
Computer, Desktop	1.5	5.43
Digital photo frame	0.6	3.74
DVD/VCR	1.8	2.09
Microwave	0.2	1.87
Phone, Cordless-Base Station	0.1	1.2
Radio	0.9	1.79
Set-Top box	0.2	4.07
Computer-Speakers	1.8	3.92
Stereo, Integrated	0.8	4.89
TV, CRT	0.0	3.51
TV, LCD	0.3	1.04
Microwave, Oven	0.1	1.87
Speaker, powered	1.4	1.77

Table 4 presents the number of houses in urban areas per Greek region and the estimated corresponding power demand required to cover standby losses. The number of houses corresponds only to the areas that are considered as urban, while a significant number of houses in some suburbs near cities are not included as these areas are not considered as a part of the urban area. Even though the houses are located in regions with different population density and profile, it was considered that the average power consumption in standby mode, should not present significant differences, due to the fact that value was a weighted average considering the appliances installed on an average representative house. Based on that, Table 4 represents the estimated electricity demand in order to support standby consumption, only for the houses in urban areas. The presented estimated values are rather high for the considered number of houses and thus, require a significant percentage of the power generation, especially in the island regions, where the power production depends on small diesel power stations, with limited support by renewable electricity sources. If someone adds the devices in standby mode operating in other types of buildings, or in houses excluded in this study, it can easily conclude that the required electricity produced by the power stations is even higher. Never-the-less the magnitude of standby losses per household is expected to be slightly reduced. This is based on the fact that the new appliances entered into the market are forced to present significant low standby losses, and due to the gradually change in Greek consumers' behavior towards adopting more energy efficient profile, and choosing devices that presents as low as possible energy and standby losses.

Table 4. Estimations of the power demand per Region in Greece

Regions of Greece	Houses in Urban areas	kW	MW
East Macedonia Thrace	115664	8829.79	8.83
Attica	714973	54581.04	54.58
Crete	101665	7761.11	7.76
Western Greece	118865	9074.15	9.07
Western Macedonia	39540	3018.48	3.02
Epirus	38977	2975.50	2.98
Ionian Islands	25798	1969.42	1.97
Central Macedonia	288890	22053.86	22.05
South Aegean Islands	74498	5687.18	5.69
Peloponnesus	106955	8164.94	8.16
Central Greece	122869	9379.82	9.38
Thessaly	143319	10940.97	10.94
North Aegean Islands	46377	3540.42	3.54
Total		**147976.69**	**147.98**

Perspectives in Standby Consumption

Up to 2005 there were not enough measurements to prove that standby power use is increasing and there was only a general feeling that this was the case. Today we are more confident on that, due to a notable number of measurements [5-8, 15, 17, 19, 23, 28-30, 32, 38, 47, 48] which prove the increase of standby electricity consumption. Manufacturers around the world have successfully reduced standby power use in some important products, like TVs, computers, and audio equipment [6-8, 10, 27, 29, 33].

New technology TVs have typically standby power less than 1W which is significantly below the 5 W ten years ago. Furthermore, the widespread use of Switch-Mode Power Supplies (SMPS) in portable electronic equipment has diminished standby power in those products. All these seem to lead to a decrease of the standby power. However, the number of products with standby power continues to increase rapidly, as it has been proven by several studies and surveys.

As the number of networked and communications products is increasing the standby consumption is not affected because these products operate most of the time in a higher-power mode (sometimes known as sleep, idle, passive standby, etc.). However, the energy consumption in all low-power modes will be increased and for this reason, many researchers have advocated focusing on energy use of all low power modes rather than only the lowest power mode [1, 4, 6-8, 29, 30, 32, 33, 52].

In developing countries, such as China and India, the standby power consumption is unquestionably increasing because consumers are rapidly acquiring products with standby. On the other hand, in the developed countries, electricity consumption in all low power modes is rapidly rising and standby is probably still rising. Therefore, from a global perspective, standby power consumption is expected to be further increased [4, 12, 14, 15, 22, 34, 39].

Until recently, there was no regulation across EU on stand-by/off-mode consumption, apart from some focused Codes of Conduct implemented on voluntary based and the EICTA voluntary agreement on TVs.

In December 2008, the EU Commission adopted the Commission Regulation (EC) No 1275/2008 for implementing the Eco-design Directive with regard to requirements for standby and off-mode electric power consumption of electrical and electronic household and office equipment. This directive is targeting to a reduction of 35TWh in 2020 and applies to any household or office product that can go into standby/off-mode. The Regulation focuses on an extensive list of equipment with stand-by/off-mode consumption, comprising four big categories of products:

1. Household appliances,
2. information technology equipment intended primarily for use in the domestic environment,
3. consumer equipment,
4. toys, leisure and sports equipment.

Table 5. EU Regulation 1275/2008/EC published on 17/12/2008. Limits for electricity consumption of equipment that can go into standby/off-mode.

Tier 1 of the ecodesign requirements	January 2010	Standby mode Reactivation function: 1.00 W Reactivation function and status display: 2.00 W Off mode: 1 W
Tier 2 of the ecodesign requirements	January 2013	Standby mode Reactivation function: 0.50 W Reactivation function and status display: 1.00 W Off mode: 0.50 W

Conclusions

The results of the measurements showed that the average standby consumption per household in urban areas in Greece is similar to the estimated values for other EU and developed countries. The Greek households present standby values that were among the lowest in EU, mainly due to the fact that the Greek household appliances market presents a “delay” to offer different types of equipment. On the other hand this fact gave the advantage that the equipment in the Greek market is already conformed to the new more strict rules about energy efficiency. Never-the-less, in Greece the power demand of appliances in standby mode is significant high and in country scale exceeds 150MW. The results of the survey show that the people in urban areas are starting to considered the energy efficiency as an important parameter, after the price and the functionality which are considered the most important criteria for selection up to now. All these facts as well as the new strict regulations adopted by the EU seems to result to a reduction in the standby consumption in EU and consequently in Greece in the near future.

References

[1] Bertoldi P., Aebischer B., Edlington C., Hershberg C., Lebot B., Lin J., Marker T., Meier A., Nakagami H., Shibata Y., Siderius H.P and Webberk C. (2002). *Standby Power Use: How Big Is the Problem? What Policies and Technical Solutions Can Address It?, Information and Electronic Technologies*: Promises and Pitfalls - 7.41, www.escholarship.org/uc/item/6xm6k7wg

[2] IEA, OECD/IEA (2001). *Things that go Blip in the Night: Standby Power and How to limit it.* www.iea.org/textbase/nppdf/free/2000/blipinthenight01.pdf .

[3] Meier A.K.. (2005). *Standby: where are we now?,* ECEEE 2005 Summer Study – *Energy Saving : What Works & Who Delivers?*, 30 May – 4 June 2005, Mandelieu La Napoule, France http://www.eceee.org/conference_proceedings/eceee/2005c/ Panel_4/4216meier/Paper/ .

[4] Bertoldi P. (2004). *The Consumer Electronics Energy Consumption and the European Policies to Reduce it, European Commission DG JRC*, http://energyefficiency.jrc.cec.eu.int

[5] de Almeida A., Fonseca P., Schlomann B., Feilberg N., Ferreira C. *Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe*, 2006, 4th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'06), June 2006, London UK. http://www.isr.uc.pt/~remodece/ downloads/REMODECE-Paper-EEDAL06.pdf

[6] EU, IEE Project no. EIE/05/124/SI2.419657. (2008). *Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe, REMODECE*. http://www.isr.uc.pt/~remodece/

[7] EuP Preparatory Study Lot 6: *Standby and Off-mode Losses TREN/D1/40 Lot 6.* Final Report (2007). www.ecostandby.org

[8] EuP Preparatory Study Lot 26: *Networked standby, TREN/D3/91-2007/Lot 26.* www.ecostandby.org.

[9] Harrington L., Kleverlaan P. (2001). *Residential standby power consumption in Australia, Project for the National Appliance & Equipment Energy Efficiency Committee*, Final Report, Australian Greenhouse Office. www.greenhouse.gov.au/energyefficiency.

[10] NAEEEP (2003). Report 2003/04 *Appliance Standby Power Consumption Store Survey 2003*, August 2003, http://www.energyrating.gov.au/library/pubs/200304-storesurvey.pdf.

[11] Ross J.P., Meier A., *Measurements of whole-house standby power consumption in California homes*, Energy. 2002, *27*, 861–868.

[12] Chen S., Yoshino H., Levine M.D., Li Z., *Contrastive analyses on annual energy consumption characteristics and the influence mechanism between new and old residential buildings in Shanghai, China, by the statistical methods,* Energy and Buildings. 2009, *41*, 1347–1359.

[13] Firth S.K., Lomas K.J., Wright A.J., Wall R., *Identifying trends in the use of domestic appliances from household electricity consumption measurements,* Energy and Buildings. 2008, *40*, 926–936.

[14] Meier A., Lin J., Liu J., Li T., *Standby power use in Chinese homes,* Energy and Buildings. 2004, *36*, 1211–1216.

[15] Asia-Pacific Partnership on Clean Development and Climate. (2008). International Initiatives to Track Standby Power Consumption: Evaluation and Verification, www.energyrating.gov.au/standby.

[16] McAllister J.A., Farrell A.E., *Electricity consumption by battery-powered consumer electronics: A household-level survey,* Energy. 2007, *32*, 1177–1184.

[17] Bredekamp A.J., Uken E.A., Borrill L., *Standby Power Consumption of Domestic Appliances in South Africa*, Domestic Use of Energy Conference 2006, Cape Town, 2006, http://www.myprius.co.za/D04 10 - Bredekamp A.pdf.

[18] Rosen K., Meier A., *Power measurements and national energy consumption of televisions and videocassette recorders in the USA,* Energy, 2000, *25*, 219–232.

[19] Tanides G., *Estimation of stand-by energy consumption and energy saving potential in Argentine households*, Energy for Sustainable Development, 2008, *XII* (4), 76-88.

[20] Fung A.S., Aulenback A., Ferguson A., Ugursal, V.I., *Standby power requirements of household appliances in Canada*, Energy and Buildings. 2003, *35*, 217–228.

[21] Rosen K. and Meier A., *Energy Use of U.S. Consumer Electronics At the End of the 20th Century*, Proceedings of The Second International Conference on Energy Efficiency in Household Appliances, Naples (Italy), June 2000, http://eetd.lbl.gov/ea/reports/46212.pdf .

[22] IEA (2003), *Cool Appliances – Policy Strategies for Energy Efficient Homes* http://www.iea.org/textbase/nppdf/free/2000/cool_appliance2003.pdf

[23] Market Transformation Programme. (2008). *BNXS15: Standby power consumption - domestic appliances*, Version 1.4. www.mtprog.com.

[24] Ueno T., Tsuji K., Inada R., Saeki O. (2005). *Effectiveness of displaying energy consumption*

data in residential houses Analysis on how the residents respond. www.ce.cmu.edu/~gdrg/readings/2006/02/21/Tsuji_EnergyDisplays.pdf .
[25] Ijuin T. (2000). *Approach to Reduce Standby Power in Japan*, Agency of Natural Resources and Energy. www.enecho.meti.go.jp/english/index.htm
[26] http://www.asiaeec-col.eccj.or.jp/databook/2007e/pdf/09.pdf (accessed June, 2010)
[27] NAEEEP (2002). Report No: 2002/08, *Appliances Standby Power Consumption*: Store Survey 2002, http://www.energyrating.gov.au/library/pubs/200208-storesurvey.pdf.
[28] Lehtomäki E. (2010). *Consumption figures of electric appliances*; Helsingin Energia. www.helen.fi/pdf/consumption.pdf .
[29] EU, IEE Project no. IEE/07/563/SI2.499206. (2010). *Standby and Off-Mode Energy Losses in New Appliances Measured in Shops*, SELINA. http://www.selina-project.eu/index.cfm
[30] Center for Climate change and sustainable energy policy, Central European University (2008). *Appliance Standby Power Consumption Store Survey 2007/2008 Hungary*. http://www.energyrating.gov.au/library/pubs/2008-standby-storesurvey-hungary.pdf
[31] RISO Inc. (2009). *Power Consumption: The Hidden Costs of Copiers and Printers*. http://us.riso.com.
[32] http://eetd.lbl.gov/EA/Standby/standby.html. (accessed June, 2010)
[33] EU Green Paper on Energy Efficiency or Doing More With Less. 2005. http://www.europeanenergyforum.eu.
[34] IEA (2005). *Standby Power Use and the IEA "1-Watt Plan"* - Fact Sheet. www.iea.org/papers/2005/standby_fact.pdf.
[35] EU Commission Regulation (EC) No 1275/2008, (2008). Implementing Directive 2005/32/EC with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment, Offic. Journal of the EU, *L339*, 45-52
[36] http://ec.europa.eu/energy/efficiency/ecodesign/legislation_en.htm. (accessed June, 2010)
[37] ACEEE (2004). *1-Watt Standby Power for Home Appliances*. www.aceee.org/pubs/a042_a1.pdf
[38] Energy Efficiency Branch, BC Ministry of Energy, Mines and Petroleum Resources (2009). *Regulatory Impact Statement for Standby power Consumption*, http://www.empr.gov.bc.ca/EEC/Strategy/EEA/Pages/default.aspx .
[39] Electrical and Mechanical Services Department, Energy Efficiency Office (2008). *Reducing Standby Power Consumption*, Hong Kong, www.ensd.gov.hk.
[40] Blok K., *Enhanced policies for the improvement of electricity efficiencies, Energy Policy.* 2005, *33*, 1635–1641.
[41] IEC 62301: *Household electrical appliances – Measurement of standby power*.
[42] IEC 62018: *Power consumption of information technology equipment-Measurement methods*.
[43] IEC 62075: *Safety of electronic Equipment within the field of Audio/Video, Information Technology and Communication technology.*
[44] IEC 62087: *Methods of measurement for the power consumption of audio, video and related equipment.*
[45] Voltech Instruments Inc, (2008). Standby Power technical Article, Rev: 86-653/1, www.voltech.com. (accessed June, 2010)
[46] www.energielabel.ch (accessed June, 2010)
[47] http://eetd.lbl.gov/EA/Standby/summary-table.html (accessed June, 2010)
[48] Valentova M., Knapek J. (2009). Myths *and Facts on Standby Power Energy Saving Potential-Czech Republic Case Study*, www.aaee.at/2009-IAEE/uploads/fullpaper_iaee09/P_544_Valentova_Michaela_31-Aug-2009, 19:47.pdf.
[49] Lebot B.. (2003). *Reducing Standby Power Waste to Less than 1 Watt: A Relevant Global Strategy that Delivers*, Energy Globe 2002, The World Award for Sustainable Energy. www.iea.org/papers/2002/globe02.pdf .
[50] Degallaix L. and Klemola N. (2007). *Consumer Relevant Eco-Design Requirements for Standby and Off-Mode Losses*, www.eupconsumer.eu/download/2nd CF meeting 19 October 2007/position_paper_lot6_IM.pdf .
[51] Varman M., Mahlia T.M.I. and Masjuki H.H. *Method for calculating annual energy efficiency improvement of TV sets*, Energy Policy. 2006, 34, 2429–2432.
[52] Nordman B., Siderius H.-P., Harrington L., Ellis M., Meier A., *Network connectivity and low-power mode energy consumption*, EEDAL2009, 16-18 June, 2009, Berlin, Germany, pp.1091-1101.

Possible savings for audiovisual electricity demand. A study based on detailed electricity measurements in 387 Swedish households.

Egil Öfverholm (main author)

The Swedish energy agency

Peter Bennich, Torgny Björn

The Swedish energy agency

Inger Norstedt

Former Head of Testlab, The Swedish energy agency

Abstract

In general there has been a considerable increase in performance of white goods over the last 15 years. As is well known, one of the main reasons for this is the introduction of the energy labelling scheme. The development for other appliances on the EU market has up to now not been that impressive – lighting and consumer electronics being two clear examples. However, since the implementation and recast of the ecodesign directive together with the recast of the energy labelling directive in the past few years, this situation changes rapidly. *E.g.*, the electricity use of domestic lighting is expected to be reduced significantly in the near future, due to the ecodesign regulation on domestic lighting that came into force in 2009.

Consumer electronics is particularly interesting in this context. Being one of the sectors in the domestic electricity use with the highest increase during the past decade, it is now a question what the impact of the ecodesign and energy labelling measures targeted on this appliance group will be. What is the theoretical potential? Will the regulations coming into place be effective enough to realise this potential?

The Swedish energy agency carried out an extensive measuring campaign during 2005 - 2008 in apartments and detached houses. The ambition was to measure most of the end-use equipment in ordinary homes, with respect to energy use, user patterns etc. Part of the dataset consists of computers and audiovisual equipment, including combinations thereof. Being based on measurements in 387 households, of which 40 were measured during a full year and the rest during one month, it is one of the largest datasets of this kind of appliances in the world.

In this study, we present detailed information on the electricity use for TVs for various types of households, etc.

Finally, the data represents a time period pre ecodesign and energy labelling for consumer electronics, so by scaling up the data we try to assess the electricity use on a national level and the possible savings when replacing inefficient equipment to more efficient equipment. Hopefully we will be able to launch another monitoring campaign in a couple of years, in order to actually measure the difference in electricity use before and after the regulations have started to have an effect.

Introduction

Based on data from the Swedish measurement campaign in 387 households (See appendix 1 for more details) we have attempted to analyse the potential savings of TVs in a scenario where the old

TVs are replaced by new, more efficient ones – a scenario that is expected as a result of the ecodesign regulation[1] and the energy labelling regulation[2] for TVs now being introduced in the EU.

We have measured all TVs in the households. The range is 1 to 5 TVs per household. These are designated TV1, TV2 etc in the following Sections. TV1 is the TV using most energy per year, next comes TV2 etc. Most data presented are based on more than 30 TVs, but for most TV4 and TV5 we have fewer than 30 measurements.

We have also measured all other equipment connected to the TVs, such as VCRs, DVDs, set top boxes etc. However they have not been measured individually but in a cluster. The composition of such a cluster varies indefinitely, so we have abstained to analyse them.

As the households have been randomly selected in order to reflect Sweden's population regarding type of family, we believe that the results represent the national level reasonably well. The data has been logged in 10 minute periods during a month or a year. Most of the measurements were made over a month and have been scaled up to a year using a seasonality correction factor. This has been described in [1].

Structure of the paper
In the next Section, the methodology for calculating the possession, operational times and consumption of the TVs in the households are described. As will be obvious, simple averages of e.g. operational times might be misleading when trying to assess the saving potentials in scenarios with replacement of old TVs to efficient TVs. Furthermore, our result of the operational time of the most frequently used TV deviates from the assumptions made in the ecodesign and labelling directives.

In the following Section the results are presented. Results for a detailed assessment of the saving potentials are also presented. Even with a rather conservative guess of the power consumption of the replacement TVs it is clear that the saving potential is substantial.

Methodology for calculations of the energy consumption of the TVs

If we were to calculate the annual consumption ignoring the difference between on-mode and standby-mode, it would be a simple task to just integrate the power over a specific time, as can be done with any simple power meter. But since the data recorded offers a more detailed analysis, more care has to be taken, as can be understood from figure 1 below. In the figure, the **duration curve** for one TV in a household, in this case measured over a full year, is displayed[3].

Basically three regions can be seen from left to right: the on-mode, the standby-mode, and the off-mode. So if we can just distinguish between the different modes, both the operational times (average use in [h] per 24 h) and the energy consumption can be calculated. Furthermore, by treating each TV in the households separately rather than as a group of TVs, necessary since the rated power (depending on size and technology) and operational time varies between TV1, TV2 etc, it is possible to also calculate the values for all individual TVs in the households.

Even with this in mind, as is clear from the figure, it is not easy to identify the power in on- and standby modes. How can we treat this problem?

[1] COMMISSION REGULATION (EC) No 642/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for televisions.
[2] COMMISSION DELEGATED REGULATION (EU) No 1062/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of televisions
[3] It is important to note that the y-axis displays 10 min averages of the energy consumption [Wh/10 min], so in order to get a more familiar understanding of the values, *i.e.,* expressed in [W], just multiply by a factor of 6. Thus, the peak value in the figure of 20 Wh/10 min corresponds to 120 Wh/h = 120 W.

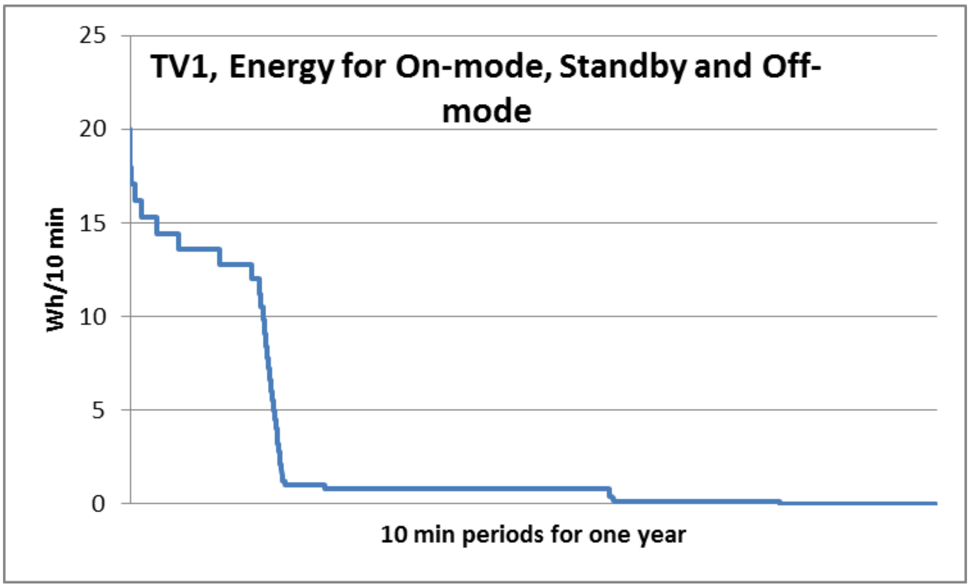


Figure 1. Duration curve for a TV in a household. The curve consists of 10 min rms-average energy data points [Wh per 10 min].

First of all, it is important to understand the different regions more in detail. The first slope, ranging from 20 Wh/10 min to 13 Wh/10 min, corresponds for the most part to the variations in the on-mode consumption itself, which often varies as a function of the luminance. The second, more steep slope, from 13 Wh/10 min down to 1 Wh/10 min, is a result of the 10 min measurement period: naturally, there will be a distribution of a mixture of on- and standby/off-modes in the 10 min averages.

The third, mostly flat region from 1 Wh/10 min to zero Wh/10 min corresponds to the standby-mode, whereas the fourth and last region equal to zero corresponds to the off-mode. (Actually, the standby-mode also has a steep region when entering into the off-mode region, but it is not so clear on this scale.)

Based on this, an algorithm was developed to identify the **breakpoints** between the on-mode and the standby-mode, and between the standby-mode and off-mode. The last one is easy to identify, since it only requires to find the data point where the values starts to be equal to zero. But the breakpoint between the on-mode and the standby-mode is much more difficult to identify, since the shape of the curves varies from case to case, as well as the standby power.

In brief, a combination of a simple derivative algorithm and a threshold condition was then used. The derivative was calculated by two moving averages (20 points) following each other; when the difference between the two was below a certain threshold, the slope was identified to be rather flat, meaning in theory that the standby region was identified. However, occasionally the slope in the on-mode region (in the interval 20 Wh/10 min to 13 Wh/10 min) was partly so flat that the algorithm erroneous identified that as the standby-region. Therefore, a threshold condition was added: the data values also had to be below 2 Wh/10 min (i.e. standby power = 12 W, a value found to work well) to ensure that it was actually the standby region that was entered.

In this way, the breaking point between the on-mode and the standby-mode was also identified.

In the next step, two simple integrations were performed: the first one, integrating from the first data point to the first breaking point, yielded the on-mode energy consumption, whereas the second one, integrating from the first breaking point to the second point, yielded the standby-mode consumption.

Furthermore, based on the breaking points, the relative operational times for the different modes were easily calculated by taking the ratio between each data point interval to the total number of data points.

The results of these calculations are found in the next Section. In the following Section, a refined method is presented, necessary in order to allow for assessing the saving potentials.

Results: The situation 2005 – 2008 (pre ecodesign and energy labelling)

In this Section, we present some of the results of the monitoring campaign, which describes the situation before the ecodesign regulation for TVs begun to apply in January 2010. The calculations were done according to the method presented in the previous Section.

Number of TVs per household

In table 1 below the number of TVs is presented. It is interesting to note that every household have at least one TV, and that the number of TVs increases rather rapidly with family size.

Table 1. The number of TVs per household

Ownership of TVs					
No. of persons	TV1	TV2	TV3	TV4	TV5
1	100,0 %	15,4 %	1,9 %		
2	100,0 %	51,9 %	10,8 %	0,8 %	
>2	100,0 %	70,7 %	32,0 %	12,2 %	4,4 %

Operational times of the TVs

See table 2: The first TV, TV1, is on for 4 hours and 50 minutes per day **on average**[4], which is more than the assumption of 4 hours made in the ecodesign and labelling regulations. Earlier studies on "TV on" have relied on surveys with the question "How many hours do you watch TV every day". However, that is clearly not the same thing as how many hours per day the TV is on.

Table 2. The amount of hours per day the TVs are in on mode, standby and off.

	TV1	**TV2**	**TV3**	**TV4**	**TV5**
>2 persons On	5,6	2,0	1,7	1,0	1,1
>2 persons Standby	5,4	8,2	7,2	13,3	8,7
>2 persons Off	13,1	13,8	15,2	9,7	14,2
2 persons On	4,6	1,6	1,0	0	0
2 persons Standby	5,7	7,8	8,8	0	0
2 persons Off	13,7	14,6	14,3	24	24
1 person On	4,5	3,2	0	0	0
1 person Standby	5,8	10,6	0	0	0
1 person Off	13,7	10,2	24	24	24

[4] To be precise, the average is a weighted average combining the results of the on-mode for TV1 in table 2, weighted by the number of households in figure 3 below.

A deeper analysis of the operational times is shown in figure 2, which reveals that the average really hides a large spread in operational time. In the figure, the on- and standby-mode for "TV1" for all households[5] are shown.

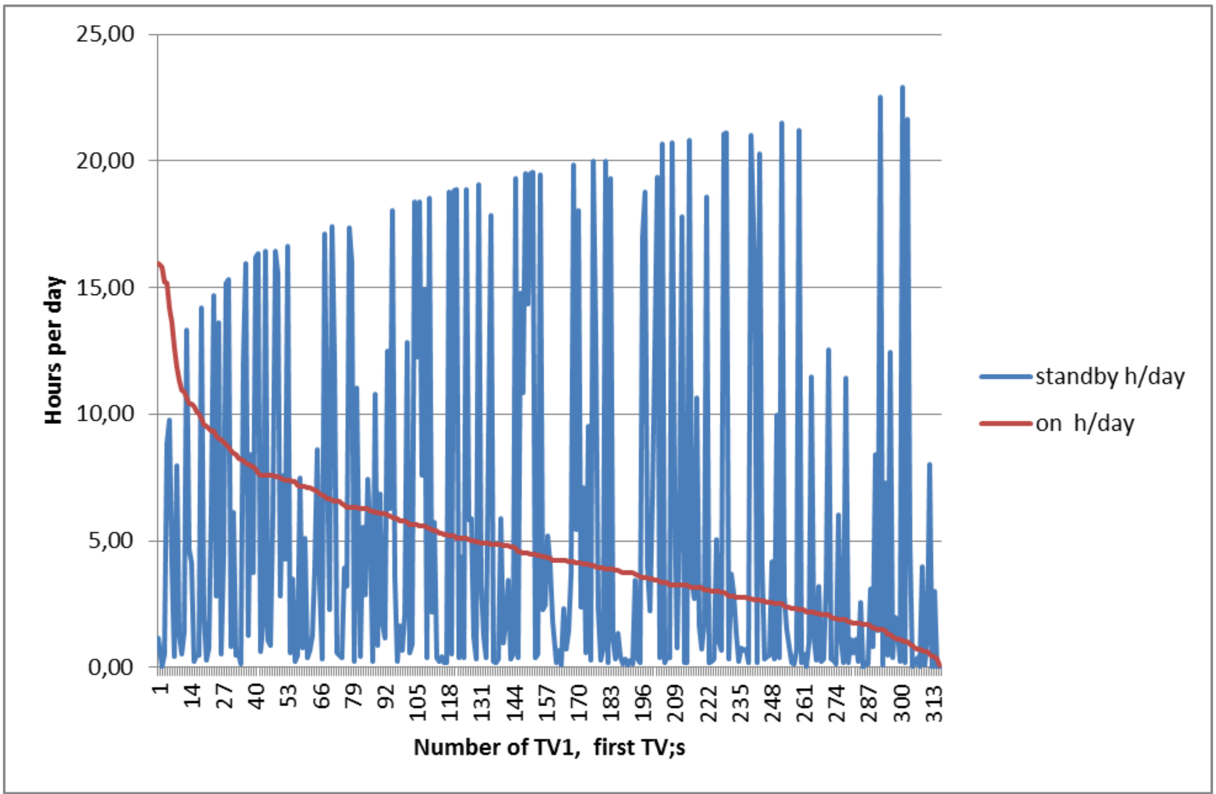


Figure 2. Variation of on-mode and standby per day for TV1.

The highest value for on-mode, 16 hours per day, was found in a high income family with two small kids (one and three years old). They lived in a flat in Stockholm. The TV was a 21" (CRT) and the measurement was done in June. We have not been able to interview the family.

Finally, in table 3 the energy consumption for the different categories is shown. In the following Section the savings for each of these categories will be presented.

Table 3. Measured energy consumption

		Measured energy, in kWh/year					
On-mode	number of persons	TV1	TV2	TV3	TV4	TV5	**Sum**
	>2	204,0	32,1	8,7	2,2	0,9	248,1
	2	152,0	16,8	1,6			170,8
	1	136,0	10,0				146,1
Standby	>2	5,6	6,0	1,6	1,4	0,4	14,9
	2	5,5	4,6	1,6			11,7

[5] The number of TVs we could observe in this case was 313 out of total 387 due to the filtering process within the data processing.

		Measured energy, in kWh/year					
	1	8,2	2,0				10,3

Results: Assessments of the saving potential

In this Section, the saving potentials if the old TVs were replaced with new, efficient ones, is presented. Starting from the discussion in the Section on methodology, figure 3 below shows the same duration curve as figure 1, but now with two square areas added. The first square shows the equivalent area of the on-mode consumption, and the second square the equivalent area for the standby consumption.

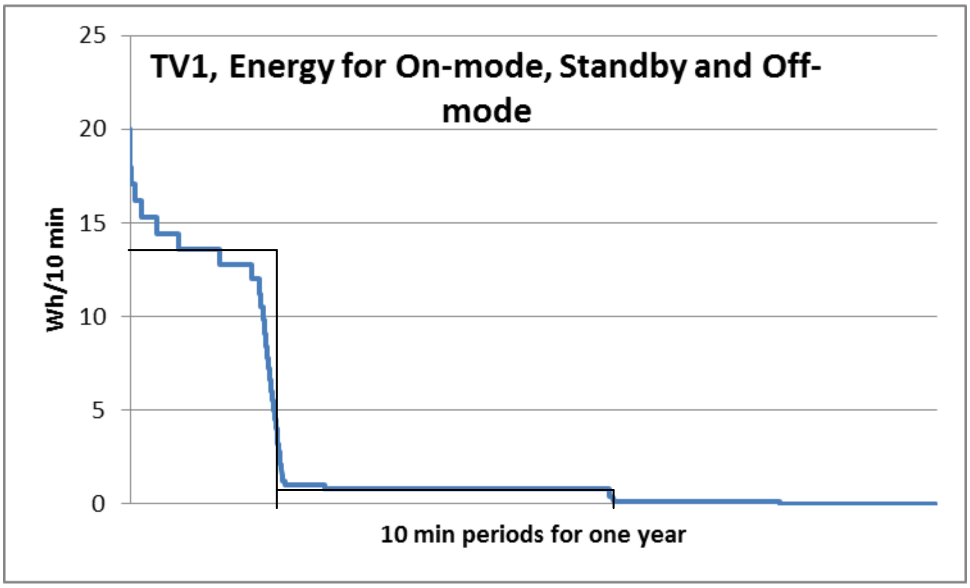


Figure 3. The duration curve for a TV in a household is the same as in figure 1. The added boxes for the on-mode and standby-mode equal the same area as the integrated areas for each mode; see text.

So, in order to assess the saving potential, we simply replace each area with another one which has a smaller area, corresponding to the efficient TV. *I.e.*, the width (determined by the breaking points; the operational times) is fixed[6] whereas the height is lower, corresponding to the lower nominal power in on-mode and standby-mode of the new TV.

It should be noted that we do the assumption that the new TV has a power consumption independent of luminance, such as LCD/LED TVs. If not, it would be necessary to mimic the variation in the on-mode (as in the first part of the curve in figure 1 and 3) and scale the new curve accordingly.

Finally, in order to get a common measurement period for all TVs, all data were scaled up to annual values, as will be clear below. We also added a manual filtering process which further reduced the amount of TV;s.

The efficiency case

We replaced the first TV in the household with a TV using 60 W and with a standby of 0,2 W. This corresponds to a 40" TV of Best Available Technology (BAT). The reason why we chose 40" was that the majority of TVs sold in Sweden last year had this size. A few of these replacements actually increased the annual energy demand, but in most cases we saw a considerable decrease.

As replacement for TV2 to TV5 we chose a 30 W 20" TV. Observe that these changes were only done in the database not in reality.

[6] Another possibility not investigated here would be to also explore the savings gained by reducing the time in on-mode and standby-mode.

Table 4. The size of TVs in the households

Size, TV	TV1	TV 2	TV 3	TV 4	TV 5
Inch average	30	22	20	20	23

There were three TVs bigger than 42", two 50" and one 46". Please note that the data collection was made between 2005 and 2008 and that there is a considerable turnover of TVs at present.

Table 5. Savings after switching to BAT TVs

		Savings in kWh/year					
On mode	Number of persons	TV1	TV2	TV3	TV4	TV5	**Sum**
	>2	97,8	16,8	3,4	1,0	0,4	119
	2	56,6	8,2	0,6			65
	1	41,8	4,9				47
Standby	>2	5,1	5,6	1,4	1,3	0,4	14
	2	5,1	4,4	1,6			11
	1	7,9	1,9				10

Observe that the savings in table 5 are savings and not the resulting energy consumptions.

Discussion

In the near future 3D TVs and even larger screens can increase the energy demand, but at the same time performance might increase with use of amoLED for example. Increased functionality (internet, spotify and more PC interaction etc.) might increase future "on-hours". Even if it is difficult to predict future trends we believe that the current activities to promote efficient TVs like the EU label and the SEAD (Super-Efficient Equipment and Appliance Deployment) awards program will encourage manufacturers to move in the direction of the BAT TVs we have used in our study.

Scaling up to the national level

Se figure 4 below for a Swedish example. We structured the data in the household groups; 1 person, 2 persons and more than 2 persons in order to get big enough samples. In the main report, see [2], the households were structured in another way including retired persons.

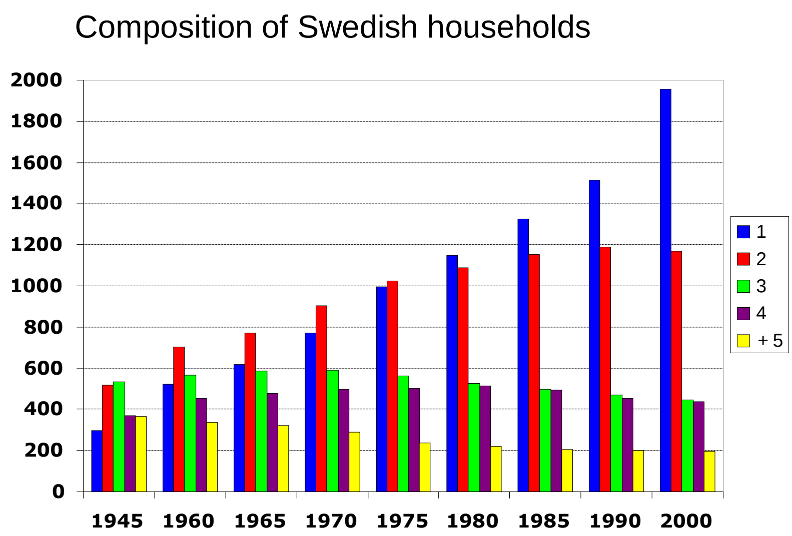


Figure 4. Historical development of the composition (nr of persons per households) of Swedish households. The unit on the y-axis is [nr of households x1000]

Unfortunately the latest reliable data on household composition is from 1990. After that estimates have been done. We have taken data from 2000 in order to estimate national savings.

Table 6. Rough calculation of possible national savings

1 person household – 1,95M*(47+10)=	**111**	**GWh**
2 person household – 1,19M*(65+11)=	90	GWh
>2 person household – 1M*(119+14)=	133	GWh
Sum	335	GWh

For comparison it can be mentioned that the total energy demand for household electricity in Sweden is 19,5 TWh.

Summary

When starting this TV analysis project we anticipated that "on-power" would be a single level. That was not the case and it caused a considerable effort to solve the problem

The amount of "on-hours" for the TVs measured, are 4h and 50 minutes. The corresponding value assumed for the ecodesign and EU-label is only 4 hours. This means that you would have to add 20% to the energy value given on the EU-label, in Sweden at least.

There is no typical "on-hours" level – the variation is big, from zero to 16 hours in our case.

Percentage savings for the most used TV replaced with BAT is between 34 and 49% depending on family size.

References

[1] Bennich 2011, "The need for seasonal correction functions when calculating the annual electricity use of appliances based on shorter period measurements", submitted to ECEEE 2011.

[2] Zimmermann 2009, End use metering campaign in 400 households in Sweden, assessment of the potential electricity savings, Eskilstuna. See

http://www.energimyndigheten.se/Global/Energifakta/F%c3%b6rb%c3%a4ttrad%20energistatistik/Festis/Final_report.pdf

Appendix 1

The metering project – Description and methodology

Selection of households

The selection has been done in cooperation with the Swedish statistics agency, “Statistics Sweden”, where households representing different types of families in combination with the type of house or apartment in terms of age and location (big town, small town, countryside), have been chosen.

Geographical aspects

Although it is difficult to achieve a truly representative selection (in statistical terms), we have strived to achieve as a varied selection as possible. However, the geographic spread was limited to be within the region of Lake Mälaren, since it offers the desired variety of households within a practical distance. But in order to check for factors due to geographical location, especially regarding lighting use since this probably varies as a function of latitude and season; a few households were chosen from the far north (Kiruna) and south (Malmö). Preliminary results indicate no particular dependency of latitude.

Enquires

The invited households were asked to fill in a detailed enquiry, with questions on the socio-economic background (address, age, gender, income etc), technical information on the dwelling (including heating system, for houses), and finally the possession of appliances. In particular, questions on the manufacturing model of white goods and TV:s was also included. This information will be used in future analysis of correlation between stated energy performance (via the energy label, for white goods) and actual energy performance.

In addition, the electric installers also filled in a detailed installation sheet which complemented and, in some cases, corrected the enquires.

Measurements

The number of loads in a typical Swedish home may be substantial; in all it can easily be over 60 loads. Thus, to measure them all was a difficult task and required a combination of direct and indirect measurements. It was performed in the following way, based on the concept used in the EURECO-study, [Zimmermann 2009]:

- As much as possible was measured in the switchboard by means of special wattmeters, namely the total consumption, stove and oven, freezer, fridge etc.
- The other appliances (TV, PC, etc) were measured by serial meters placed between the socket outlet and the appliance.
- The energy (in Wh) of nearly all end-uses in the homes are measured individually as 10 min root-mean-square (rms) averages, making it possible to manipulate individual load data on a time-scale ranging from 10 min up to a full year.
- Light sources were measured in an indirect way: light sensors measured when the lamps were on and off; together with information of the nominal power it was then possible to calculate the energy consumption (energy = power * time).
- Estimations were used for loads that could not be measured directly (apart from light sources), e.g. when there was a mix of free and fixed installations fed from the same fuse.
- The in- and outdoor temperature was measured.
- By aggregating data in different combinations, everything from the load in individual homes to specific loads (*e.g.* TVs) for all households is possible to get.

As an example of the load curves, see fig A.1 below:

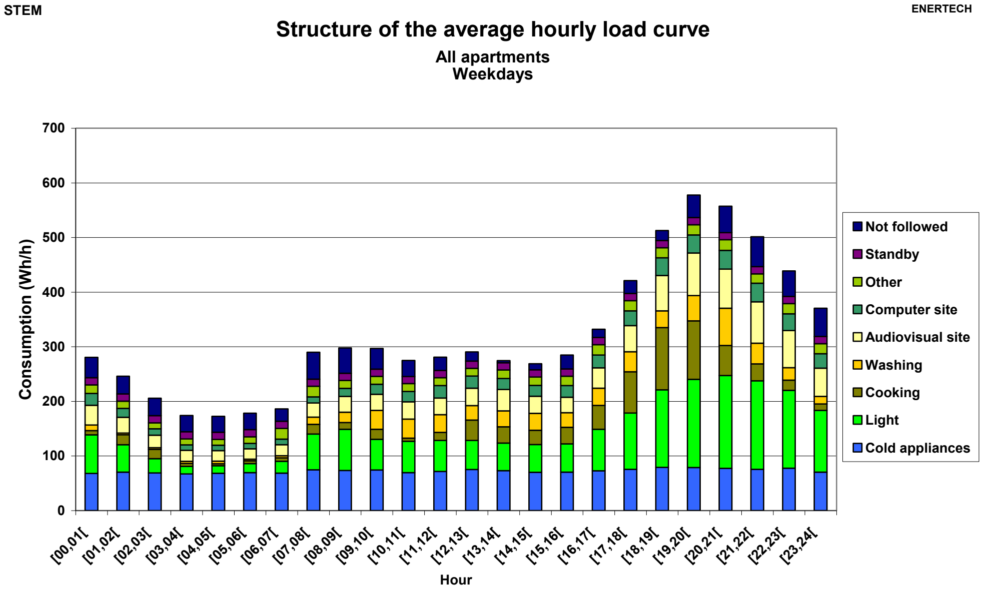


Figure A.1 Example of load data, 24 hour

In order to make the measurements cost-effective only 40 measurements have been carried out for a whole year, 20 per year. The rest have been measured for a month, 20 each month, evenly distributed over the year and then scaled up to annual values using correction factors as described in this paper. All in all, measurements were performed in 200 houses and 187 apartments.

The measurements started in September 2005 and ended June 2008. The measurements, most of the analyses and reporting have been carried out by Enertech, a French company, in collaboration with YIT, a Swedish electric installer. By means of time resolved measurements, 10 minute root mean square (rms) data on an appliance level, detailed load curves on a daily, weekly, monthly and yearly basis were achieved. In total there are more than 200 000 million data points. The database is now in SQL format. It will be located at the Swedish Energy Agency. See also http://www.energimyndigheten.se/sv/Energifakta/Statistik/Forbattrad-energistatistik-i-bebyggelsen/Matning-av-hushallsel-pa-apparatniva-/ This is also the place where reports will be available.

Long Term Trends of Standby Power Consumption in Australia and Future Policies

***Paul Ryan*[1]*, Allan Booth*[2]**

[1] EnergyConsult, Australia

[2] Department of Climate Change and Energy Efficiency, Australia

Abstract

Over the last 10 years, the Australian Government has facilitated the collection of standby power measurements of appliances in stores in order to examine long term trends in standby power and highlight areas for national policy action. Almost 8000 appliances have been measured in various modes and trends have become apparent in various technology categories that show standby power is still a major issue. The measurement approach taken by the Australian Government has been utilised in other countries and regions with data being collected to establish baseline trends or to monitor compliance with policy interventions. This data has been used to support policy development in Europe and Australia.

The measurement methodology and the results of the long term monitoring are discussed, as well as the trends used to establish baselines for policy cases in Australia. Examples of comparisons between countries are used to show the effectiveness of different policy interventions and the importance of continuing data collection. For example, in Australia microwave ovens have shown a decrease in average standby power but have not trended any lower since 2006, while in Korea, the average standby power of microwave ovens is now approaching 1 Watt. The potential of future Australian policy options are also illustrated.

Introduction

In 2001, the Australian government facilitated the collection of standby power measurements of appliances being sold in stores, as part of a wider study[1]. Since 2001, surveys have been conducted every year that target new appliances being offered for sale in selected major retailers (measured in situ). This information was extremely valuable because it provided trend data in standby power for new products. The database of almost 8,000 measurements enabled policy makers to quickly establish which appliance types have increasing or decreasing standby trends for many appliances with annual data from 2001 to 2010. In 2008 the database was expanded to include other countries in order to provide a source of global information on standby power trends.

These standby power surveys[2] and other studies are essential to providing evidence for government policy development. Data from Australia has been used in the development of the European Commission studies on standby power [3], and other international programmes. The long term data collection will provide trend information for the development of future Australian government policy. In 2010 the Australian government released a discussion paper on home entertainment products and will release a Regulatory Impact Statement (RIS) on standby power limits for other equipment in 2011. These developments are described in the following sections.

Measurement Approach

The annual standby power survey has been undertaken in Australia since 2001, with approximately 600 to 1000 appliances measured every year. This survey is performed in two separate time blocks to ensure a broader range of appliances are included and this approach has enabled the survey to include seasonal products such as heaters and air conditioners. Typically, up to eight different stores are surveyed each year. During the survey, additional information is collected regarding the features/functions of each appliance, i.e. screen size of monitors and TVs, style of appliance, and other characteristics such as wall mount vs. portable air conditioner and price. This information assists in the analysis of the data and identifying any trends in appliances. For example if a group of appliances with the same features are all found to be high-energy consuming products then the presence of that feature could explain the extra power. The survey also records the presence of an Energy Rating label or an ENERGY STAR label on appliances. Appliance brand and model number are recorded to prevent duplication of measurements. While there was no specific selection process, most of the available stock on display in the store was measured.

For each appliance, power consumption was measured while the appliance was in use, in standby (passive and/or active) and off, where applicable. Clearly for many appliances such as washing machines and dishwashers, it was impractical to measure the appliance in use or for those products where there is an Australian Standard that adequately covers the ‘in use’ mode consumption and hence data was not collected.

Appliances and equipment with a “standby mode” may include any product that consumes power while not performing its primary function. A simple definition of “standby” is when an appliance is at its lowest power consumption when connected to mains power, even if the appliance is turned off (lowest power mode that can be influenced by the user). However, “standby” is better defined under various modes and for the purpose of the survey, the Asia Pacific Partnership International Basket of Products Survey[4] definitions were used:

- ***Power – In Use (on):*** the power used by the product when performing its primary function.
- ***Power – Active standby:*** Active standby is when the appliance is on but not performing its main function. For example, the DVD may be on but is not playing or recording. This mode is usually only present in devices (a) where there is a mechanical function which is not active (e.g. DVD drive or motor) but where power circuits are on, or (b) where a device has a battery and the device is charging
- ***Power – Passive standby:*** When a product or appliance is not performing its main function (sleeping) but it is ready to be switched on (in most cases with a remote control) or is performing some secondary function (e.g. has a display or clock which is active in this mode). This mode also applies to power supplies for battery operated equipment (portable appliances which are intended to be used when disconnected from the base station) when the appliance is not being charged (disconnected).
- ***Power – Off***: The product must have a power switch located on the product. Off mode is when a product or appliance is connected to a power source but does not produce any sound or picture, transmit or receive information or is waiting to be switched “on” by the consumer. If the product has a remote control, it cannot be woken by the remote control from off mode – it can only be activated via the power switch on the product. No display should be active in off mode. While the product may be doing some internal functions in off mode (e.g. memory functions, EMC filters) these are not obvious to the user. An LED may be present to indicate off mode.

While there are some limitations of data collected in the field, the annual Australian standby survey is considered to be a highly useful data source to establish trends and technology differences at a product level. However, there are a number of possible limitations with respect to individual readings, which must be considered by users of the data when this is examined at an individual record level. These include:

- As a general rule, simple meters are usually used for field measurements – while these usually have good accuracy under most conditions, there may be some readings where they may give a higher level of uncertainty (i.e. when there are very low power levels, very poor power factor or a high current crest factor).
- For field measurements it is not possible to regulate supply voltage, harmonics or other test conditions during the measurement. However these factors generally have a small influence on the measured result.
- Product behaviour cannot normally be monitored for a long period in the field due to the limited time available as there is a need to cover a large number of products. While a valid reading can be obtained for most products within a few minutes, some products may take longer to stabilise because they go through a start-up sequence once the power is first connected: this may or may not be obvious to the user or be recorded via the power meter. Some products may wait in a different state when the power is first connected (e.g.

some products may download information when the power is initially connected or monitor other inputs for a period).

- In retail outlets, remote controls or other accessories are sometimes not available (these may be locked up for security purposes) so some product modes may not be accessible for some products. Also some products of interest which are on display in retail outlets may be hard to access for measurement if they are locked up for security purposes.
- While the methodology used for most store surveys is to measure all available floor stock in all available low power modes, the presence and prevalence of a model on display in a retail outlet does not necessarily reflect its sales or prevalence in the stock of installed products.

Regardless of these limitations, the standby store survey has provided valuable trend information for policy analysis and support for Australian research as detailed in later sections. The measurement of standby power in retail stores in Australia is now being promoted by the Asia-Pacific Partnership on Clean Development and Climate (APP), the IEA 4E Standby Power Annex[5] and in the European Union with SELINA[6]. These projects have encouraged the measurement of over 10,000 products, with Australia and Korea now providing time series data as more than three surveys have been undertaken.

Data quality is further improved by the use of verification procedures, where: the field measurements are shared with each manufacturer and a reasonable time period is provided for comment. Where suppliers do not respond within a defined and reasonable period, the base assumption is that the data is accurate and is therefore verified by default (i.e., non response by a supplier for an indefinite period is not considered to be disputation of the results). Comparison of field measurements to any manufacturer data available through marketing material and/or web sites is also made.

The majority of appliances were measured using a portable meter (Sparmeter Model NZR 230 or AD Power Co, Wattman model HPM-100A). The meter used for measuring TVs energy usage was a Yokogawa digital power analyser Model WT200.

Scope of Data Collected

Data is available for 52 categories of appliances as shown in Table 1, with ten years of time series measurements for some appliance types. Certain categories of appliances were measured annually (such as Microwaves) however several categories were not measured each year due to their availability in the retail store or a change in focus of scope of data collection for that particular year[7].

In 2008, the survey approach was adopted internationally by the Alignment of National Standby Power Approaches Project. The Basket of Products survey[8] is the key component of this project and has been designed to enable consistent collection of data on standby power, resulting in a representative set of standby measurements. Data is also now available from the International Standby Power Database9 for the key Basket of Products appliance categories for the following countries: Australia, Korea, Canada, China, USA, India, New Zealand, Czech Republic and Hungary. The database provides over 500 charts and tables displayed as histograms, time series and “box and whiskers” The Box and Whisker graph format enables the maximum and minimum consumption data to be displayed along with the mean, the median and percentile data. Fifty percent of all readings fall within the brown box with the upper edge being the 75th percentile and the lower edge representing the 25th percentile. Therefore the upper whisker represents the range of values in the highest 25% of readings and the bottom whisker represents the lowest 25%. An example of this graphic is shown in Figure 1.

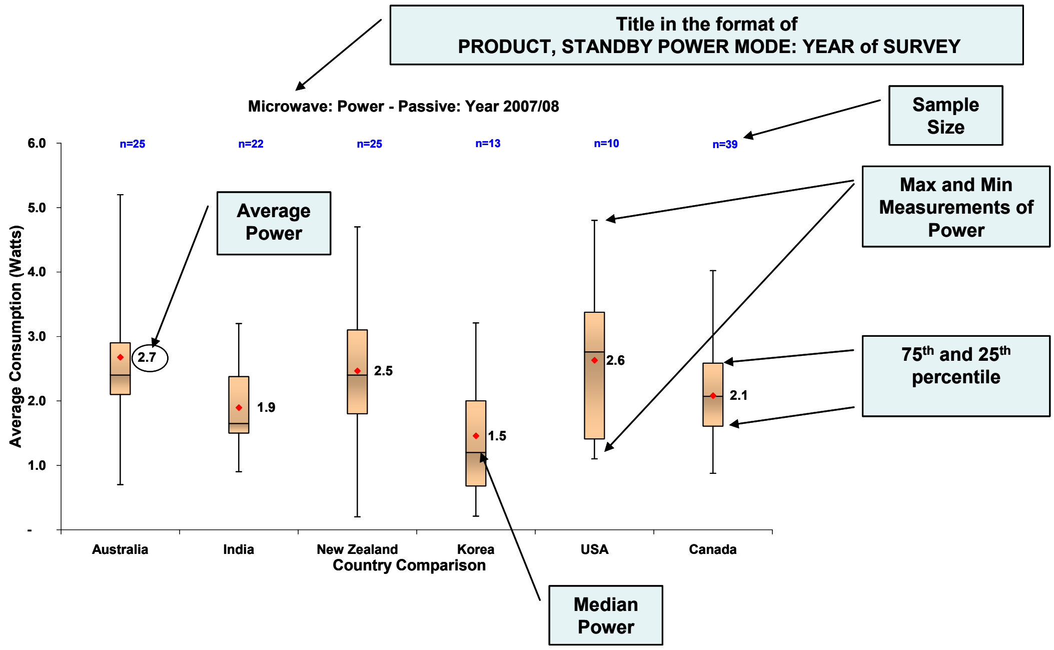


Figure 1: Example of Box + Whiskers Country Comparisons Graph

Table 1: Total Number of Appliances Measured in Australia by Category

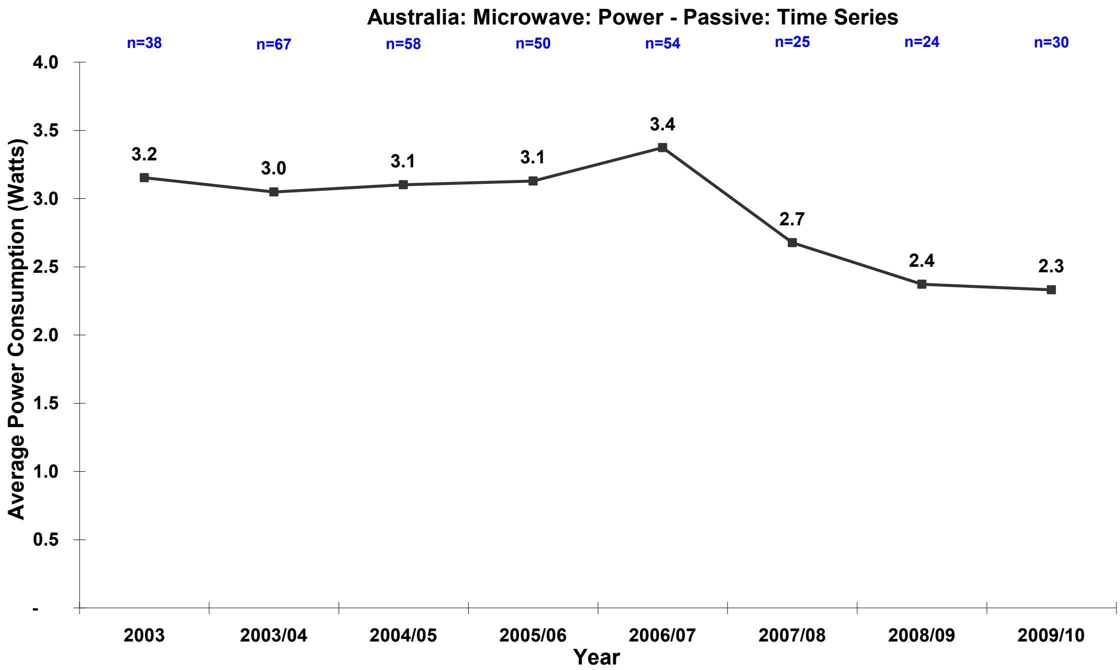
Appliance	**Total Number**	**Appliance**	**Total Number**
Air Conditioner	201	TV/VCR/DVD	17
AV Receiver	328	VCR	192
Dishwasher	271	Washing Machine Front Loader	220
Dryer	195	Washing Machine Top Loader	319
DVD Player	470	Breadmaker	80
DVD Recorder	127	Computers - Home Theatre Box	17
Espresso Machine	210	Computers - Laptop	105
External Power Supplies	177	Computers - Monitor	246
Fan	52	Computers - Speakers	42
Gas Water Heaters	16	Cook top	41
Hard Disk Recorder	143	Facsimile	32
Heater - Electric portable	265	Game Console	1
Heater - Gas	58	Home Theatre System	167
Home Entertainment Other	195	Multi Function Device	190
Home Theatre System	35	Oven	10
Juicer	93	Printer – Inkjet	150
Microwave	481	Printer – Laser	79
Set Top Box	194	Range Hood	54
Stereo - Integrated	504	Stove	26
Stereo - Portable	272	TV – Projection	101
Subwoofer	212	Hand - held vac	78
Toaster	130	Computers - Desktop	141
TV - CRT	571	computers - other accessories	7
TV - LCD	244	Cordless Phone Base Station	25
TV - Plasma	167	Shredder	10
Digital photo frame	7	Games Console	1
Total Number			**7969**

Results

To demonstrate the effectiveness of the data collected, and the usefulness for policy analysis, the following items of equipment have been chosen for discussion in this paper: Microwave ovens, LCD TVs, and DVD/Video Disc Players.

Microwave Ovens

As shown in Figure 2 passive standby for microwave ovens had remained stable since 2003/04. However the last two surveys recorded a statistically significant decrease in consumption which may indicative of a downward trend. Interestingly, while the Korean models consume half the standby power of their Australian counterparts, the trend lines are almost identical for the last three years.



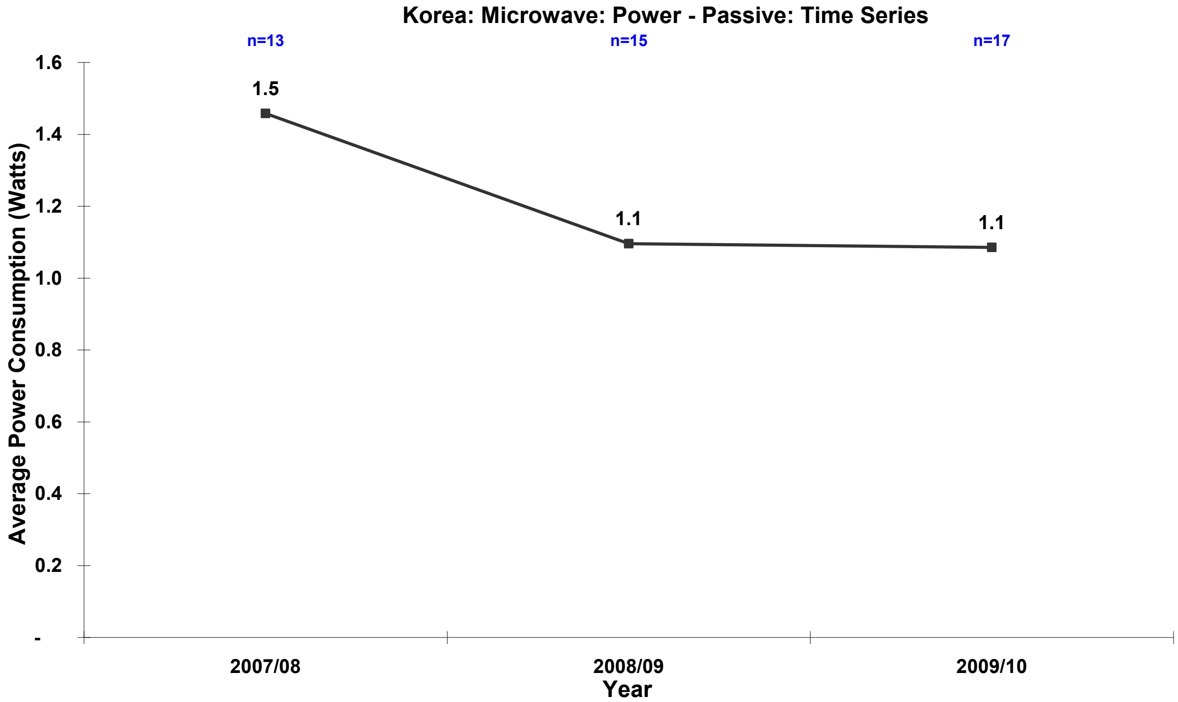


Figure 2: Australian & Korean Time Series Data – Microwave Passive Mode

In 2009/10 three countries were able to collect data on Microwave ovens in passive standby. Both Korea and China found average consumption and the range of consumption to be lower. As shown in Figure 3, Australia's average consumption was more than double Korea's at 2.3 watts with most Australian models being higher than the highest consuming Korean model. This difference in standby power consumption is likely to be due to the introduction of a mandatory "*warning label*" for products that do not meet the 1 Watt limit established by the Korean Government in July 2009 [10].

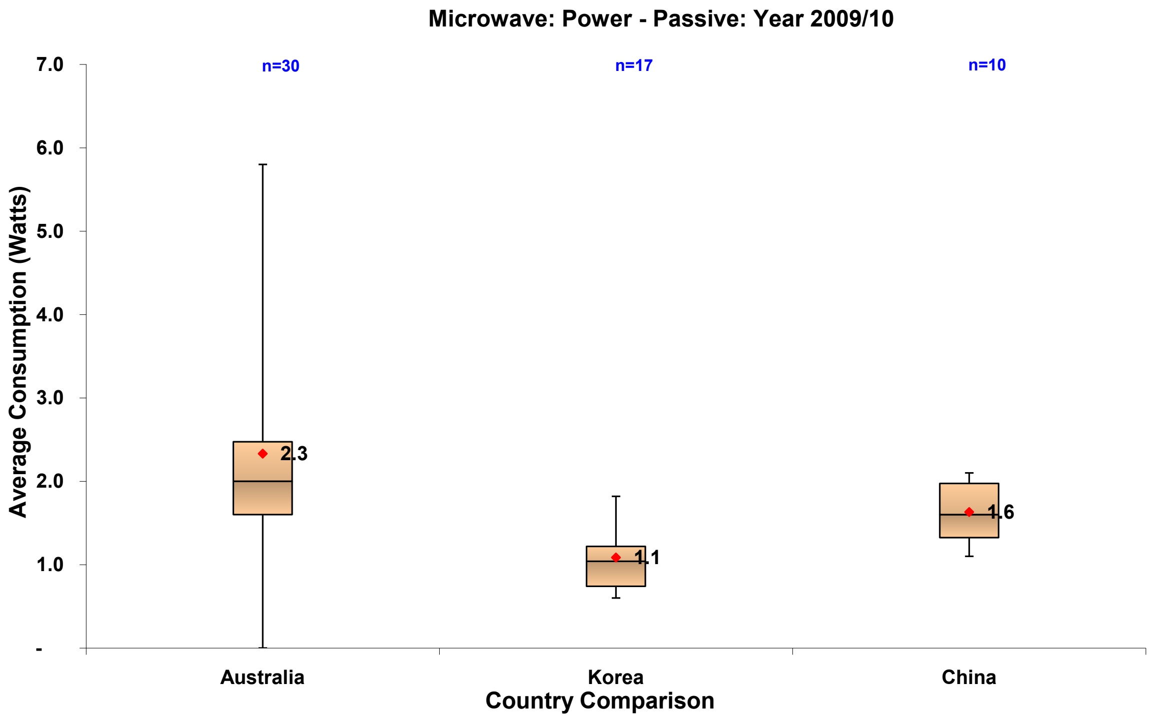
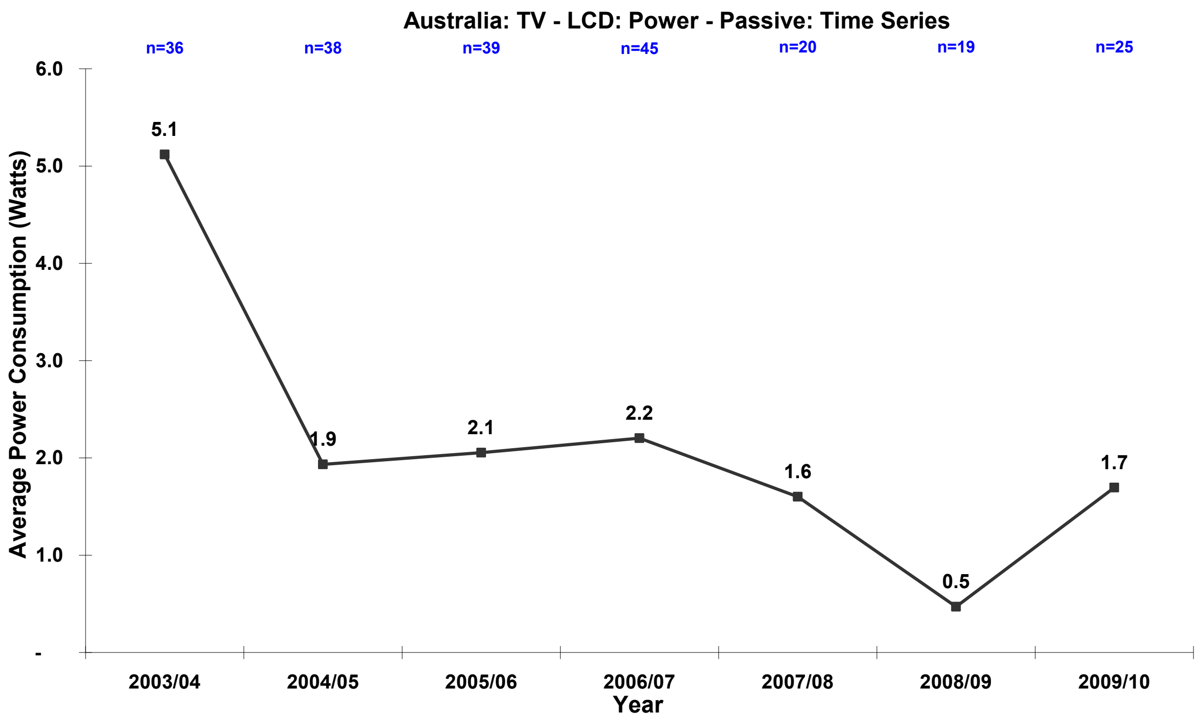


Figure 3: 2009/10 International Comparison Microwaves Passive Mode

LCD TVs

The average passive standby power consumption of LCD TVs in Australia has ranged from 1.6 to 2.2 watts from 2004/05 to 2007/08, as shown in Figure 4. The results would indicate that the decline recorded in 2008/09 was perhaps a sampling anomaly with the 2009/10 average returning to previous consumption levels. However, the histogram shown Figure 5 for 2009/10 shows the average is distorted by one extreme outlying result, which when removed would see the average fall below 1 watt (0.8) instead of 1.7 Watts. These results are shown in Figure 4 along with Korean data for the last 3 years. In Korea's case there is a clear downward trend with average passive standby in 2007/08 measured at 1.2 watts falling to 0.2 watts in 2009/10. Again the downward trend in LCD passive standby power in Korea is probably a result of their "warning label" where TVs have been required to use the label if power consumption is higher than 1 Watt from August 2008.



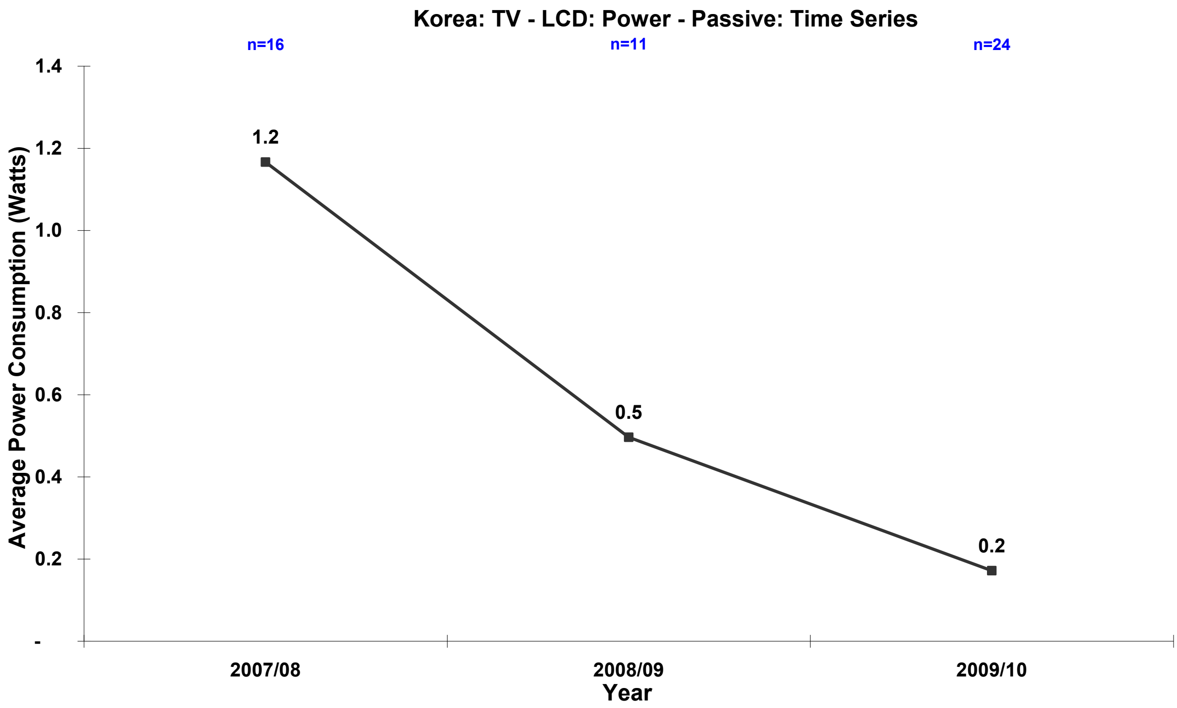


Figure 4: Australia and Korea Time Series Data – LCD TV Passive Mode

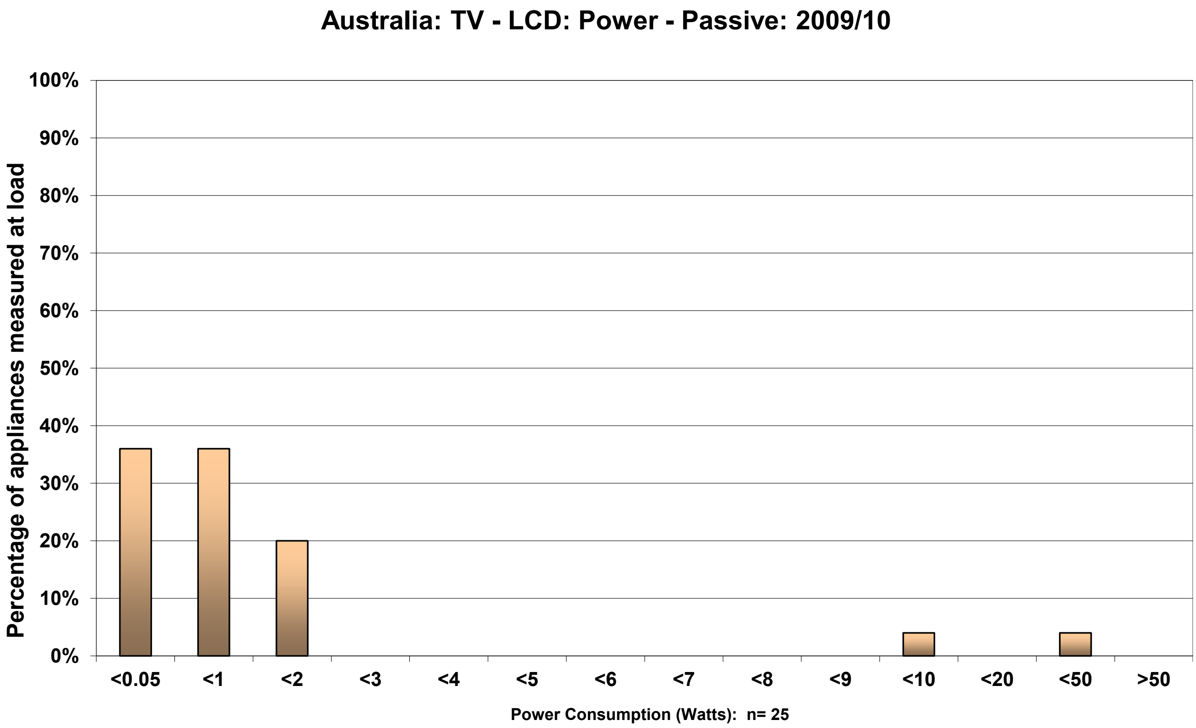


Figure 5: Australian 2009/10 Histogram Data – LCD TV Passive Mode

DVD/Video Disc Players

The time series data for DVD players sold in Australia in passive standby mode is shown in Figure 6. This chart demonstrates that after a slow and steady decrease in average consumption the last two years have seen a slight increase. This increase is not statistically significant and is quite small (0.3W) but indicates a stabilising of the downward trend.

Active standby average consumption in 2009/10 was the lowest ever at 7.4 Watts. If this result is mimicked in the 2011 survey this may indicate the first real downward movement in this mode. These results are shown in Figure 7.

Both passive and active standby power consumption in Australia shows that, with more effort, suppliers can reduce standby power, however government policy action may be required. Figure 8 shows that 25% of Australian products consume more than 1 Watt in passive standby mode in 2009/10. The introduction of maximum standby power limits by the European Commission at the start of 2010 [11] and the warning label for DVD players in Korea from mid 2010 are some of the government actions that are likely to result in lower passive standby power for products sold in all countries,. Australia is considering a broad policy measure for home entertainment products as described further in this paper.

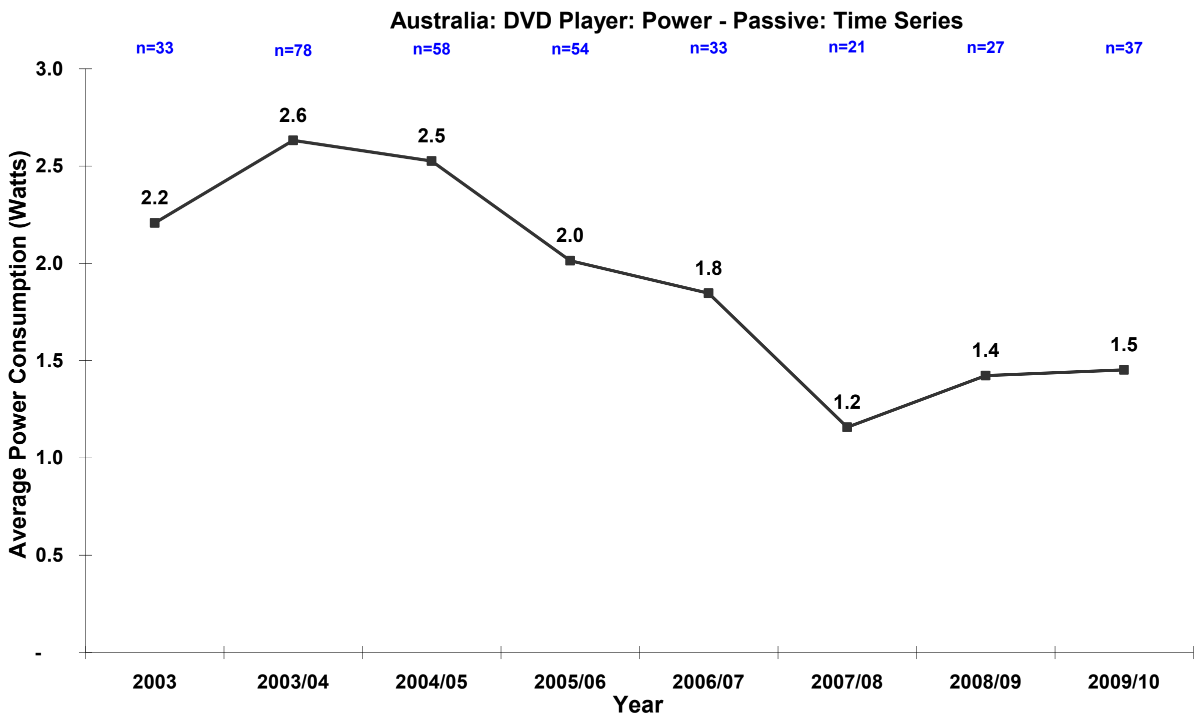


Figure 6: Australian Time Series Data – DVD Player Passive Mode

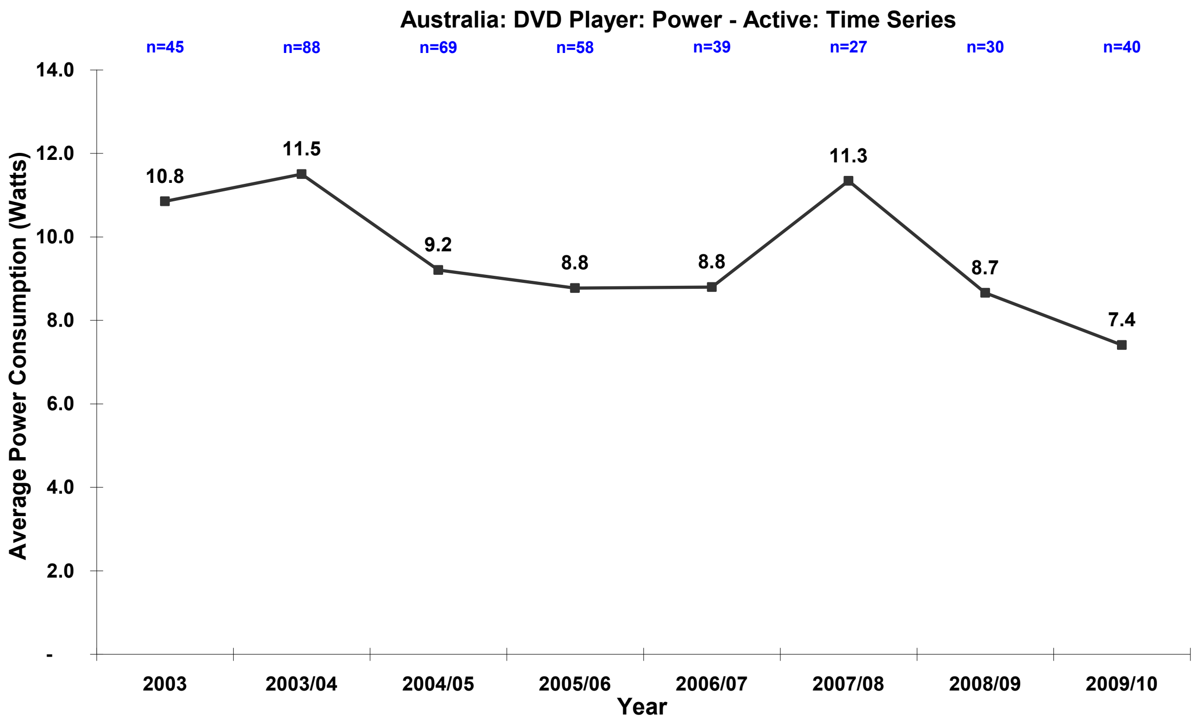


Figure 7: Australian Time Series Data – DVD Player Active Mode

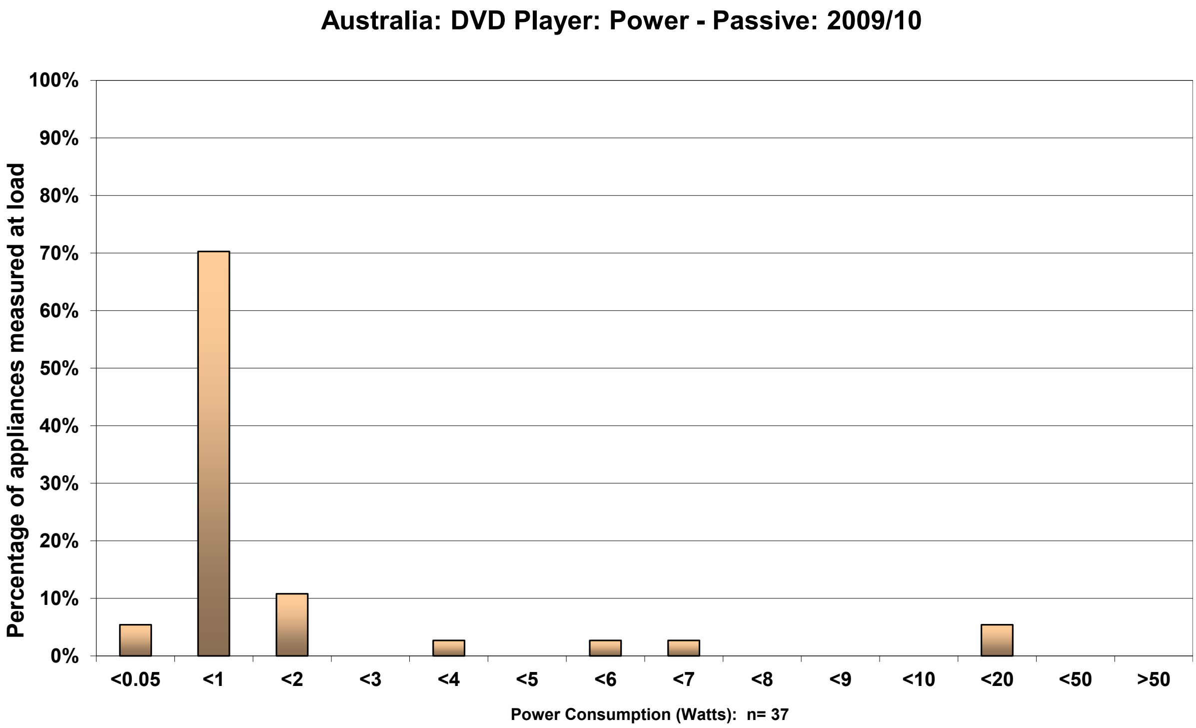


Figure 8: Australian 2009/10 Histogram Data – DVD Player Passive Mode

Figure 9 compares the passive standby mode for DVD players in Australia, Korea and China The average consumption is similar across all countries however the range of passive standby power consumption varies significantly, with products sold in Australia showing the widest outlier's while Korean products have a relatively large spread in the 1 to 3 watt range.

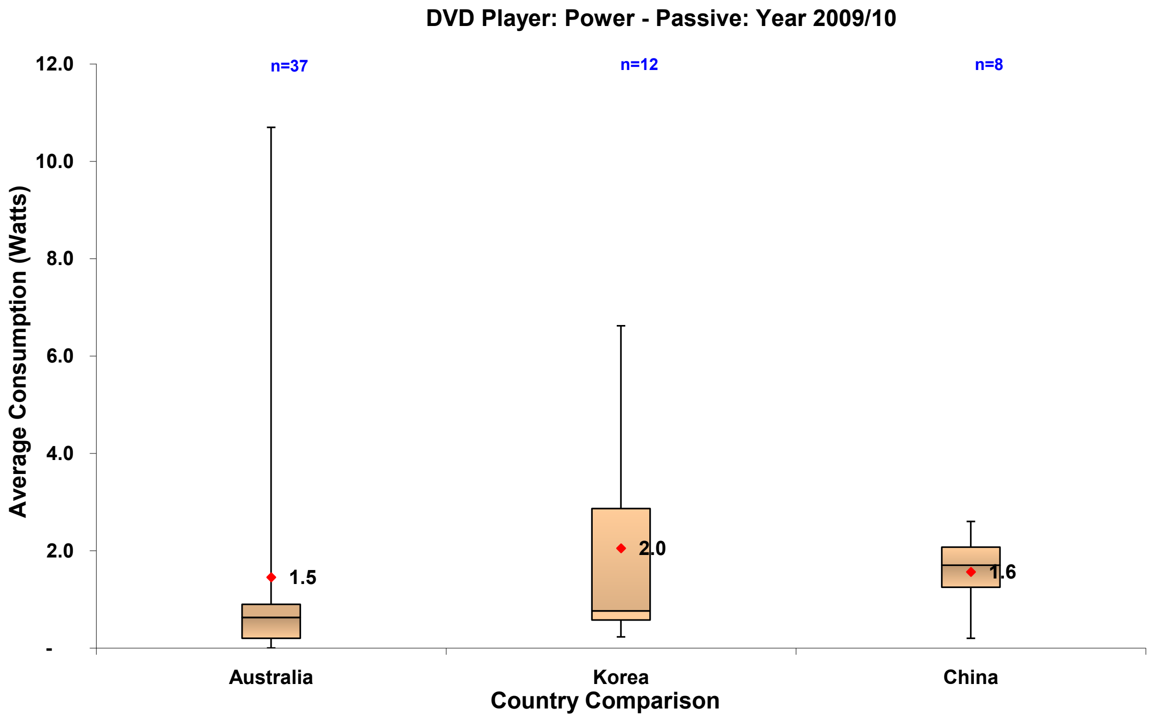


Figure 9: 2009/10 International Comparison DVD Passive Mode

Future Policies

In 2010, the Australian government released a product profile focusing on a set of Home Entertainment products (HEP) [12]. This was released as an initial document for consultation purposes with industry stakeholders on the potential for energy efficiency improvements and the scope of different international policy approaches. In early 2011 the Australian Government will release a Regulatory Impact Statement (RIS), a regulatory requirement, on the implementation of a horizontal 1 Watt standby policy. A RIS will provide government with feedback on proposed regulation, which is this case, is to improve existing levels of energy efficiency of standby mode (and off mode) in residential products and appliances that are not already covered by energy efficiency regulation [13].

Home Entertainment Products

A recent report commissioned by the Australian Government "*Home Entertainment Products: Product Profile*[1] estimates the energy impact of HEP and provides evidence through business as usual (BAU) modelling that significant energy savings are possible when compared potential requirements of existing International Programmes.

The scope of this product profile includes many common HEP, excluding TVs, which are already subject to Energy Labelling and MEPS. The devices covered include, Simple set-top boxes (STBs), Complex STBs, Video Players, Video Recorders, Home Theatre System Players, Home Theatre Recorders, Audio Amplifiers and Games Consoles. Figure 10 gives the annual sales for a range of HEP types, both past sales and forecast. The chart shows sales can exceed one million units p.a. and that some product sales can rise rapidly and falls away to virtually nothing within the space of fifteen years such as DVD players.

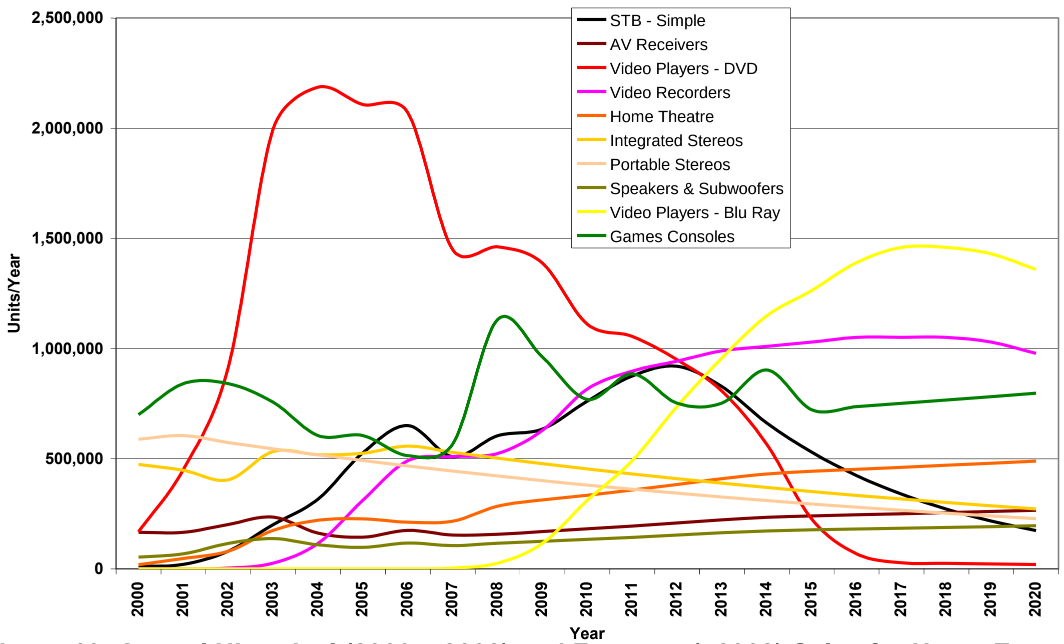


Figure 10: Annual Historical (2000 – 2008) and Forecast (>2008) Sales for Home Entertainment Products

Source: Gfk Australia 2000 – 2008, Forecast by EnergyConsult post 2008

The annual sales of all home entertainment product types have grown rapidly since 2000, with the exception of portable stereos which have fallen slightly. Over five million units of HEP are now sold annually, with the single most popular product currently being DVD players. The result is an extremely

1

high penetration of HEP in the domestic market in Australia and a significant and growing proportion of residential energy use is being devoted to these products.

The modelling in this report shows that the potential of implementing energy efficiency measures is significant. The total energy consumption attributed to HEP could be reduced by 1,900 GWh pa and reduce greenhouse gas emissions by 1.4 Mt CO_2-e pa in Australia by 2020 as demonstrated in Figure 11 below which compares the BAU energy use scenario with the energy efficiency scenario (based on measures derived from existing international programmes). The potential impact of improved HEP efficiency shown in Figure 11 is based on comparing international programmes and associated assumptions with the BAU scenario.

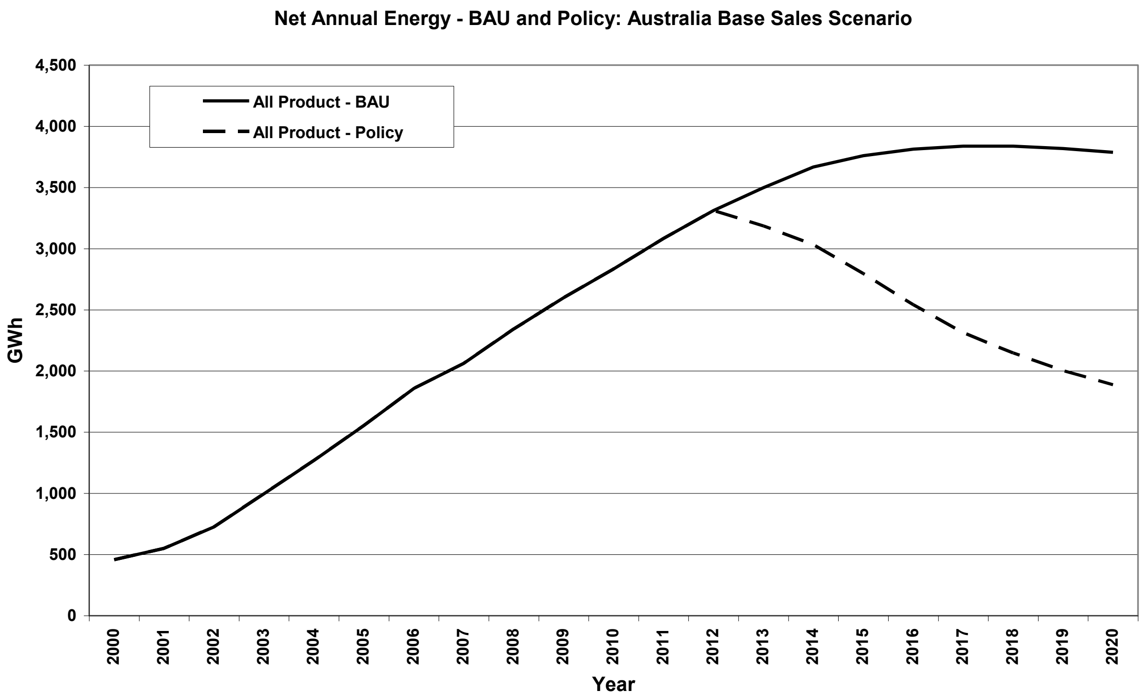


Figure 11: Business As Usual vs. Potential Energy Efficiency Scenario

1 Watt Horizontal Standby

A plan was proposed by the Australian government in March 2004 for reducing standby power of various products. However, comments on this plan by stakeholders suggested that mandatory regulations might better meet the Australian government's efficiency goals. The proposed plan has been enlarged to cover all products that use standby power that are not covered by existing or proposed regulation.

Energy efficiency measures for standby power are part of the Equipment Energy Efficiency Program (E3) — E3 is an initiative of the Ministerial Council on Energy (MCE) comprising ministers responsible for energy from all states and territories. Minimum Energy Performance Standards (MEPS) set performance requirements for an energy-using device that effectively limits the maximum amount of energy that may be consumed by a product in performing a specified task. The program prevents the sale of appliances and equipment that have a relatively poor energy efficiency performance. MEPS and labelling is a key element of Australia's response to climate change and are used to achieve other energy related policy objectives. The MEPS program currently covers 15 appliances and equipment types nationally and a further 29 products are being considered for addition to the program.

In 2011, at time of writing this paper, a RIS was being prepared for public comment by the Equipment Energy Efficiency (E3) Committee, in accordance Australian Government guidelines. The intention will be to seek feedback on proposed regulations to improve existing levels of energy efficiency of standby mode (and off mode) in residential products and appliances that are not already covered by energy efficiency regulation.

The proposed regulation will apply to all relevant equipment and appliances used throughout Australia. The equipment covered includes, but is not limited to, the products listed in Table 2.

Table 2: Products Potentially Covered by Horizontal Standby Policy

Standby Products	
Breadmakers	Clock Radios
Espresso Coffee Machines	Burglar Alarms
Gas Cooktops and Ovens	Motion Sensors and Sensor Lights
Microwave Ovens	Smoke Alarms
Rangehoods	Remote Garage Door Openers
Electric Space Heaters	

Standby mode permits the activation of equipment by remote switch (including remote control, internal sensor, or timer) and provides continuous function such as information or status displays, including clocks and sensor-based functions. In the off mode, power can be used while the product is connected to a mains power source even though it is not providing a standby function.

The RIS summarises the arguments and analysis for introducing nationally consistent energy efficiency regulations.

The E3 Committee will seek stakeholder views about the regulatory proposal and the analysis contained in the RIS, and based on the analysis and consultation with stakeholders E3 intends to put to the MCE in late 2011 a recommendation. It is anticipated that the regulatory proposal (if accepted) would commence not earlier than October 2013, and seek to improve existing levels of energy efficiency of standby mode (and off mode) in residential products and appliances that are not already covered by energy efficiency regulation. This recommendation aims to redress the continued sale of inefficient products and appliances throughout Australia. The proposed regulation would be based on internationally accepted test methods as a means of ensuring the proposed regulation is cost effective.

Conclusions

The tracking of long term trends of standby power can provide excellent information for policy analysis as well as the potential for tracking the impact of policy interventions in the future. The Australian Government has utilised more than 10 years of trend data as inputs to it latest policy analysis and will continue to monitor standby power trends as the government further develops and implements policy actions. In the future, the long term trend data will be a source of BAU trends for the evaluation of policy interventions.

Based on current trends the energy consumption of home entertainment products in both standby and operational modes will be significant and further policy development is required to address in-efficiency. The potential savings from encouraging lower standby power in products that are not currently regulated in Australia are also being investigated. The horizontal approach (i.e., coverage of a large group of appliances) promoted by the IEA is the most likely option to be developed for policy action.

References

[1] *Quantification of Residential Standby Power Consumption in Australia*, prepared by Energy Efficient Strategies and EnergyConsult 2001, Prepared for NAEEEC, Available from http://www.energyrating.gov.au/library/detailsstandby-2001.html

[2] *Standby Power Store Survey 2008-09: Interim Report (Report 2008/12)*, prepared by EnergyConsult for Department of the Environment, Water, Heritage and the Arts, Canberra, Australia, October 2008

3 *Lot 6, Standby and Off-Mode Losses of EuPs, Public Report Task 1 - 7*, October 2007, European Commission tender TREN/D1/40-2005/LOT6. Berlin, 2 October 2007

4 *Appliance Standby Survey Product Guide, Detailed Instructions of the International Standby Basket of Products Survey*, Prepared by EnergyConsult for: Department of Climate Change and Energy Efficiency Australia, 26 March 2010

5 IEA Implementing Agreement for a Co-operating Programme on Efficient Electrical End-Use Equipment (4E), Standby Annex. Information available at http://www.iea-4e.org/

6 Standby and Off-Mode Energy Losses In New Appliances Measured in Shops, a project supported by the Intelligent Energy - Europe programme. Information available at http://www.selina-project.eu/

7 *APP Alignment of National Standby Power Approaches Project: 2009/10 Data Outcomes*. Prepared by EnergyConsult for the Department of Climate Change and Energy Efficiency, Canberra, Australia, June 2010.

8 International Standby Basket of Products: Approach to tracking global standby power trends Participants Guide Available from www.energyrating.gov.au/standbydata/participants-guide.pdf

9 Website is www.energyrating.gov.au/standbydata/app/

10 *Negative Label, Positive Step Standby Warning Label and Korea's 1W Policy* - Yungrae KIM, Korea Energy Management Corporation (KEMCO), Presented at APEC Standby Power Conference - Moving Towards 1 Watt and Beyond. Tokyo, 19-21 October 2010.

11 European Commission, COMMISSION REGULATION (EC) No 1275/2008,of 17 December 2008, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to Ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment. Official Journal of the European Union, L339/45, Brussels, 18.12.2008

12 *Home Entertainment Products: Product Profile*, Prepared for The Department of the Climate Change and Energy Efficiency on behalf of The Equipment Energy Efficiency Program by EnergyConsult and Digital CEnergy Australia.

13 *Australia's Policy Plans for Home Entertainment Products and 1 Watt Standby* – Paul Ryan, EnergyConsult, Presented at APEC Standby Power Conference - Moving Towards 1 Watt and Beyond. Tokyo, 19-21 October 2010

Standby and off-mode power demand of new appliances in the market

Aníbal de Almeida

ISR-University of Coimbra

Carlos Patrão

ISR-University of Coimbra

Philippe Rivière and David da Silva

Mines Paristech

Barbara Schlomann

Fraunhofer ISI

Bob Harrison

Intertek

Abstract

For more than a decade, it has been recognized that the energy consumption in low power modes for electrical and electronic products is an important issue because it represent permanent loads (sometimes up to 24 hours per day) of a huge number of products. With the 1 W standby initiative of the International Energy Agency (IEA), several low power mode measurement campaigns have been led on a regular basis in a number of countries outside and inside Europe Union (EU). Based on these results and on the Energy-using Products Study Lot 6, the EU has prepared new regulation to limit the standby and off-mode power consumption of non-networked household electronic and electrical equipment, which is being applied since January 2010.

The IEE project SELINA carried out a large scale monitoring campaign in shops in order to characterize the low power modes of new appliances being sold in the EU market.

In order to ensure consistency of the collected data, a common measurement methodology was developed and the same high resolution measurement equipment was used by all partners. This publication analyzes the results of more than 6000 different equipments measured in the 12 EU countries involved in the project. Standby and off-mode values by product categories are analyzed and compared with data from other regions of the World. The measurements are also benchmarked against the new 2010/2013 EU standby and off mode regulation thresholds and the impact of the EU regulation is discussed.

In parallel with the measurement campaign, an awareness study of the retailers was carried out. This survey helps to understand the customers' buying motivations and the influence of retailers' advice in their choices.

An overview of the collected policies and initiatives to improve the low power mode energy consumption are reviewed.

Introduction

The introduction of energy labels, together with MEPS – Minimum Energy Performance Standards, implemented with EU Directives during the last fifteen years, has produced a positive trend in the sales of more energy efficient appliances. However there has been a fast increase of electrical and electronic loads (entertainment, office equipment, communication/internet, white appliances with embedded electronics), coupled with the proliferation of gadgets which have electronic controls, and which are typically connected to the AC supply all the time.

The relevance of the standby and off-mode energy consumption is illustrated by the fact that the IEA estimates that, even with a continuation of all existing appliance policy measures, the electricity consumption for ICT and consumer electronics will grow by almost 800% from 1990 to 2030. Next figure shows an overview of IEA projections for ICT and CE electricity consumption up to 2030.

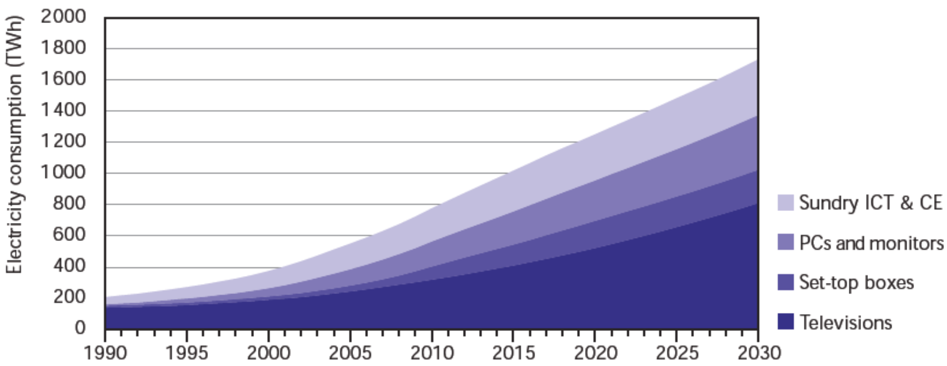


Figure 1. Projected IEA electricity consumption for ICT and CE equipment, 1990-2030 (1).

According to the IEA, by 2030, 15% of the total appliances electricity consumption in Europe could be due to standby functions. This represents the largest area of potential energy savings because efforts to introduce measures to reduce the standby and off-mode energy consumption have only started in the last 10 years. In the future, power demand will be influenced by technical improvements in the equipment introduced by manufacturers, as well as by Minimum Energy Performance Standards, such as the one recently set by the European Commission (e.g. Commission Regulation (EC) No 1275/2008 of 17 December 2008, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off-mode electric power consumption of electrical and electronic household equipment).

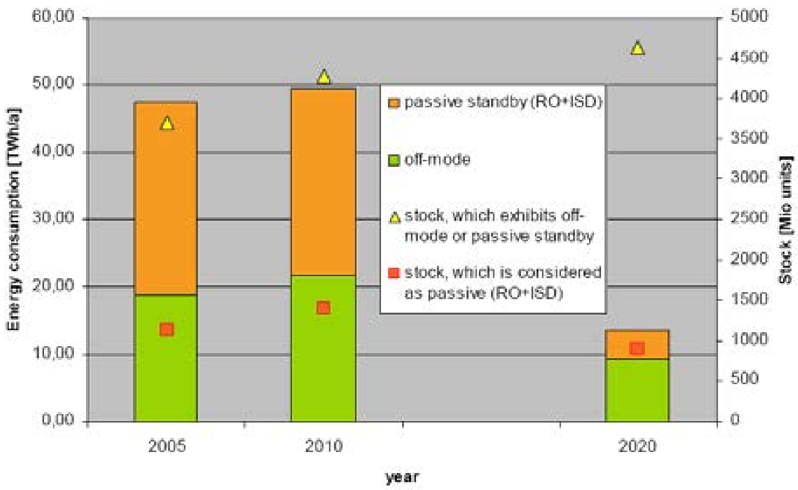


Figure 2. Development of stock and electricity consumption of standby/off mode, excluding networked equipment and assuming a 0.5W/1.0W power consumption level in 2020 (RO: reactivation only; ISD: information or status display) (2).

According to the DG TREN Impact Assessment report, the electricity consumption of electrical and electronic equipment in standby and off-mode is expected to be 13.6 TWh by 2020, due to the new requirements of the regulation. Excluding networked equipment, the expected reduction is of about 35 TWh compared to the Business as Usual (BAU) scenario that can be seen in the figure above. This represents about 4.5 billion Euros in electricity savings supposing the prices of the year 2005[1] (2).

Although significant improvements in energy efficiency have been achieved in appliances technologies, during the period of 2004 to 2007 the end-use electricity consumption increased by 2.11% in the residential sector and by 10.45% in the tertiary sector. In the tertiary sector it is a significant increase when compared with the growth rate for the period of 2001 to 2004, when an increase of 6.96% was registered (3).

Some of the reasons for such increase in the residential and tertiary sector electricity consumption are associated with a higher degree of basic comfort and level of service and amenities (particularly in the new EU member countries), as well as with the widespread utilization of relatively new types of loads whose penetration and use has experienced a very significant growth in recent years.

Office equipment (PCs, monitors, fax machines, photocopiers, printers, internet equipment, etc.) are the fastest growing electricity end uses in the tertiary sector. It is expected that this electricity consumption doubles by 2020 (4). The EL-TERTIARY European Project estimated that the office equipment electricity consumption represents around 5.3% of the tertiary sector in France, 6% in Italy, 14% in Germany and 7.5% in The Netherlands (4). Based on a recent published estimation, in 2007, more than 48 million desktop computers and 59 million laptops were acquired for non-residential applications (3).

Based on statistics data, the total standby electricity consumption of home appliances in EU-27 in 2007 amounted to around 43 TWh, which is 5.4% of the total residential electricity consumption (3).

In a recently completed Intelligence Energy Europe (IEE) Project, REMODECE (Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe - http://remodece.isr.uc.pt), the electricity use of appliances in houses has been monitored in detail (with separate metering of lighting and individual appliances) in some 1300 homes across the EU. The average measured standby power was about 40 W and electricity consumption is 305 kWh per household per year, which is about 11% of the total annual electricity consumption per household. The standby electricity consumption, for all participating countries of REMODECE project, amounts in total to about 40 TWh (5). For the tertiary sector the annual electricity consumption for the standby of office appliances in EU-27 countries is estimated to be 9.43 TWh (3).

In Germany, the share of standby is estimated to be about 6.8% or 9.4 TWh (6). Substantial technical and behavioural saving options exist to reduce standby consumption. For Germany, electricity savings of 4.6 TWh are estimated until 2020, if all saving options with regard to standby were applied. This means a halving of current standby consumption in the residential sector. On the part of manufacturers, the technical solutions for reducing standby consumption, which are mostly cost-effective, are often not applied due to possible additional costs for the manufacturer, and also because it is not a market access requirement [(3), (7)].

In 2005, the G8 leaders agreed to promote the application of the International Energy Agency's (IEA) 1-Watt initiative which aims to reduce standby requirements for all new appliances below 1 Watt by 2010, which was a positive step in the right direction.

It is generally accepted that the demand for information and communication services and technologies will sharply increase. The future power demand will be more influenced by the technical improvements introduced in the equipments by manufacturers, as well as by voluntary agreements and programmes (such as the Code of conduct for Digital TV Services, Code of Conduct on Energy Consumption of Broadband Communication Equipment, Code of Conduct on Efficiency of External Power Supplies and IEA Standby Power Initiative). Electrical and electronic equipment with standby

[1] Average electricity price in 2005 in EU-25: 13.6 Cent/kWh

and off-mode losses is a fast growing load (e.g. entertainment, information and communication technologies -ICT, set top boxes-STB). In the near future, all domestic equipment (including white goods) is likely to be controlled by electronic equipment, and will have the capability to communicate with other equipment. This situation will potentially lead to an increase in the standby and off-mode electricity consumption, if appropriate policies are not implemented.

SELINA - The European Project

The name SELINA stands for Standby and Off-Mode Energy Losses In New Appliances Measured in Shops. The SELINA project is directed to characterize the EU market in terms of standby and off-mode consumption in new electrical and electronic household and office equipment, being sold in shops, with a developed appliance specific measuring methodology. A large scale monitoring of new equipment characterized low power modes ("lopomos"), of the equipment being sold in a large sample of EU Countries. More than 6000 pieces of equipment were measured, in the period 2009-2010, before and after the entering in force of the European Regulation EC 1275/2008 regarding standby and off-mode power consumption. This will allowed the creating of an equipment online database with all the measurements made during the campaigns that can be accessed through the project website: www.selina-project.eu. The groups of products that were covered include:

- Entertainment equipment (Set Top Box, TVs screens of all sizes and technologies, DVD players and recorders, Video Projectors, Hi-Fi, Home Cinema systems, game consoles, all external Power supplies and Chargers associated with portable entertainment equipment);
- Information and Communication Technologies - ICT (Desktop and Notebook Computers, Monitors, Printers, Fax machines, wired and wireless Routers, cordless Telephones, Answering Machines, all External Power Supplies and Chargers associated with portable ICT equipment.);
- Large appliances (Washing Machines, Dishwashers, Tumble Dryers, Chillers, Air Conditioning devices, etc.);
- Miscellaneous (Electronic Controllers for central heating/cooling and solar systems, home Alarm Systems Garage Door Openers, Occupancy Sensors / Automatic Light Switches etc).

Another aim of the SELINA project was to propose a representative "basket of products" for which standby and off-mode power levels could be measured and tracked in any country around the world. This basket was measured by interested parties to compare trends in standby and off-mode power within that country and across countries.

International cooperation with institutions outside the EU, involved in similar efforts [IEA Implementing Agreement 4E (Efficient Electrical End-use Equipment) with an Annex on Standby, Energy Star/EPA in USA, Australia Standby Initiative, Swiss Federal Office of Energy] were used to promote synergies in the definition of common approaches to characterize the market and to define realistic and cost-effective performance targets which can be achieved in a short time frame.

Methodology used during the measurement campaigns

A key early objective of the SELINA project was to identify a test methodology providing a safe and accurate measurement of off and low power modes for a basket of products to be found "in store". Simulated testing of a wide range of products in replicated store conditions was put in place in the UK Intertek laboratory to develop a methodology that would provide accurate off and low power mode data measured as closely as possible to the metering criteria stipulated in the international standby test methodology standard IEC 62301.

It was accepted at an early stage of the simulated testing exercise that those measuring conditions stipulated in IEC 62301 associated with mains supply voltage regulation and harmonic content would be outside the control of an in- store test rig. Even a basic regulated supply capable of powering the wide range of products likely to be tested would fall outside the financial resources of the project and would prove impractical in the physical conditions of the "shop floor". In this context it should be noted that such a regulated supply would be required to withstand the power load of products in ”on-mode”, not just the low-power mode.

The accuracy of power meters available to the project testing teams in large quantities (a potential requirement for 120 meters was identified) at an affordable hire cost quickly became a critical issue. Although it was accepted that the selected power meters could be pre-calibrated prior to distribution to the National testing teams, no meters were found, within the budget constraints of the project, that would allow accurate low power measurement to 0.25W or less.

Fortunately, at the Consumer Electronics Show in early 2009, AD power, a Korean manufacturer of sampling power meters, introduced a low cost meter based on very new electronic design that allowed consistant and accurate firmware calibration in production. The sample sourced for testing was well within the limits specified in IEC 62301 for low power measurements (less than 1W) and for all power measurements up to 2.5kW. Arrangements were made to source all the meters required for the testing teams. These were tested for calibration before distribution against a high grade laboratory power meter at the Intertek laboratories and found to easily meet the IEC 62301 metering tolerance.

The common methodology and the equipment from ADpower – WATTMAN HPM-100A - was used by all partners in their national measurement campaigns. For the shop measurements, it was developed an excel sheet that automatically communicates with the measurement equipment, and inserted the average values for Voltage, Power factor and Power (W). This way it was possible to collect comparable values between countries and reduce human errors.

Measurement campaigns results

During the measurement campaign of the SELINA project 6318 appliances were measured, over the 6000 appliances targeted. The results for the off-mode and standby power input are presented in the next figures.

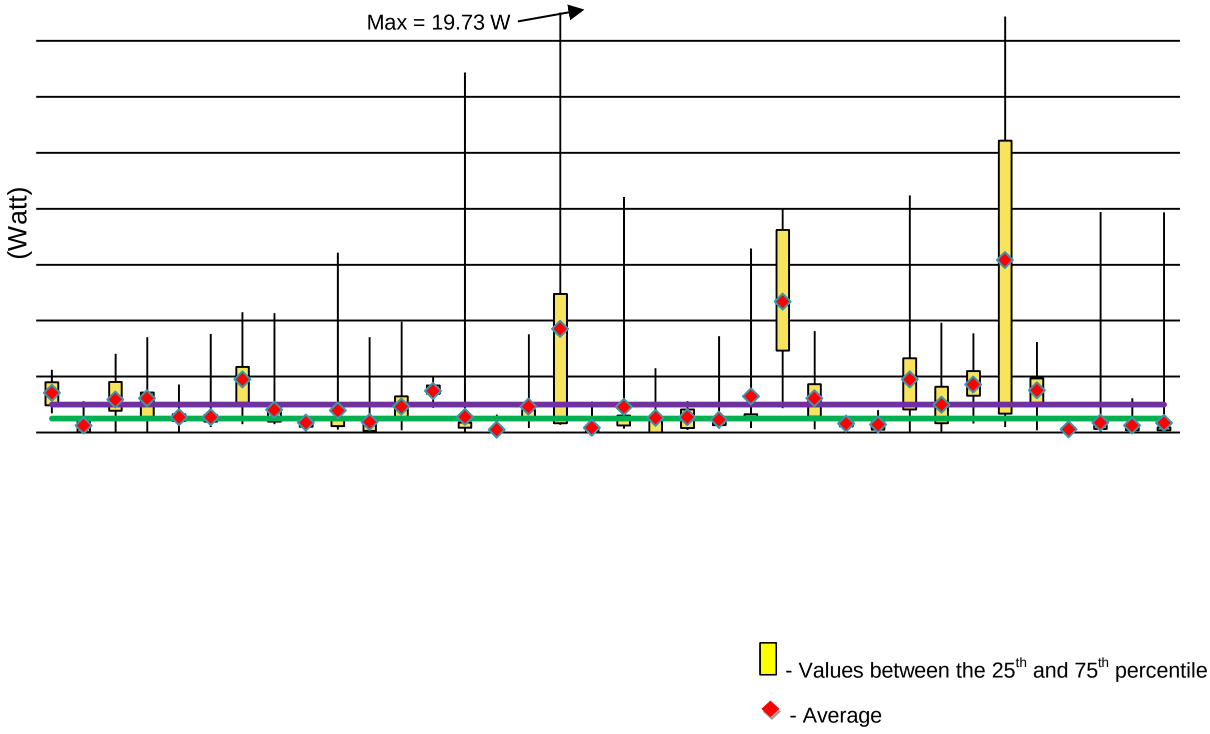


Figure 3. Off-mode input power for the basket of products[2].

2
- Some products listed on the figure are not in the EC 1725/2008 scope.

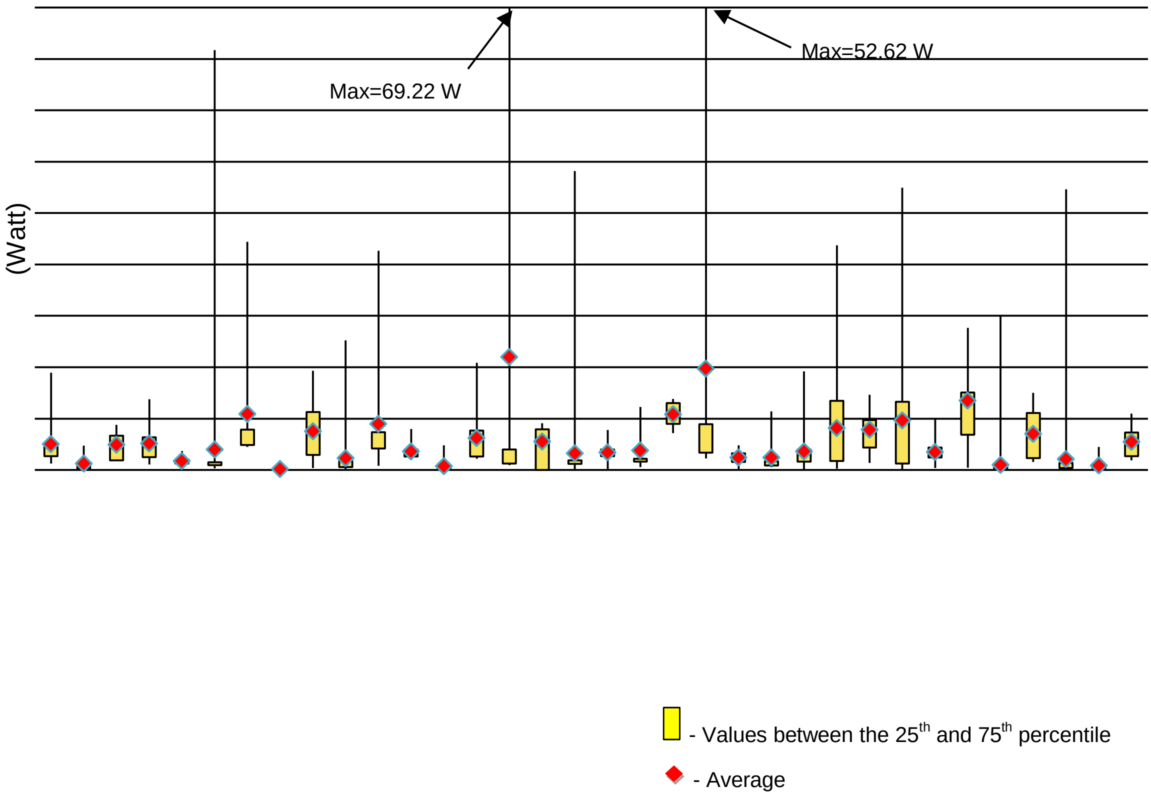


Figure 4. Standby input power for the basket of products[3].

The reason why there is a small number of measurements for example for copiers, home security systems, modems, and others is because some products were very difficult to find in shops or to get the necessary conditions to measure them. The reasons behind this are: either that there are only a few number of models being sold or exposed (sometimes only the product box is exposed – or for modems, there is no off mode and it is difficult to simulate passive mode) or that they are hard-wired.

In off-mode, Lighting-Lamp/transformer registered the highest input power with 19.7 W. Regarding the standby mode for the basket of products the highest input power registered was for game console with 69.22 W.

Copiers, game consoles, multi function devices and computer monitors are the products with the highest standby measured input power. However these high values represent a low percentage of the total measurements. It should be noted that these high values can be due to equipment damage, production defect or products with special features.

The values for off-mode input power are in general low and almost always near the EU regulation limits. In the case of the standby mode, the input power values are higher, as expected, but only slightly above the EU regulation (1 W and 2 W for 2010 limits – depending if the equipment has only a reactivation function or a display/information).

- The numbers after each product type represents the number of measurements in off-mode.
- The yellow bar represents the distribution, where 50% of the measured consumption can be found. The values placed above and below the yellow bar, represented by a solid line, correspond to the other two distributions where the other 50% of measurements can be recorded.

3
- Some products listed on the figure are not in the EC 1725/2008 scope.
- The numbers after each product type represents the number of measurements in off-mode.
- The yellow bar represents the distribution, where 50% of the measured consumption can be found. The values placed above and below the yellow bar, represented by a solid line, correspond to the other two distributions where the other 50% of measurements can be recorded.
- No EU regulation thresholds is presented in this figure because they depend on each products characteristics (presence of display/clock or not)

In the next figure, the values for input power in off-mode and standby of all the measured equipments (even the ones not in scope of the EU regulation), is compared with the regulation limits, showing the percentage of products over the EU regulation threshold.

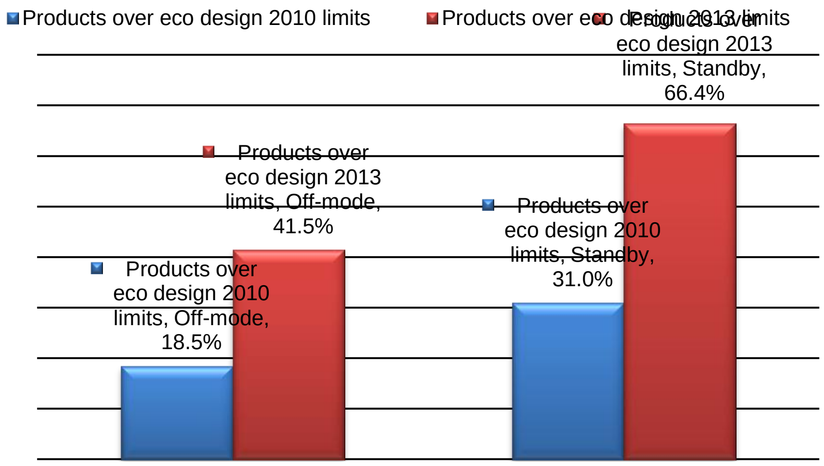


Figure 5. Compatibility of the appliances input power with the EC 1275/2008 regulation threshold.

The previous figure shows that 18.5% of the measured products presented power values higher than the 2010 EC 1275/2008 regulation threshold in off-mode. For standby this value reaches 31%. When a comparison is made with the 2013 EC 1275/2008 regulation threshold these values are doubled.

If the appliances not in the EC 1275/2008 scope were removed from the above analysis, a decrease of 4 % for the non-compliant products over standby eco-design 2013 limits was visible. The other values would be affected with differences of less than 0.5 %.

Because the measurement campaign started in 2009 and ended in June 2010, with the EC regulation entering into force in January 2010, it was expected to identify a significant difference between the values measured before and the ones measured after the entry into force of the regulation. However, the 2010 measurement results tend to show that the number of products over the EU regulation threshold did not vary significantly (see next table).

Table 1. Difference between 2010 and 2009 measurements related to measurements out of EU regulation limits.

	Off-Mode	Standby
Difference between 2010 and 2009 Products over eco design 2010 limits	2.6%	-1.7%
Difference between 2010 and 2009 Products over eco design 2013 limits	-1.7%	2.1%

The values of the above table suggest that manufacturers of most products already adopted their production to the DGENER Lot 6 EuP study on standby, which started in 2006. The low difference between 2009 and 2010 measures could also be due to remaining product stocks.

Anyway it appears that future market surveillance will be helpful to verify and to clean the market as intended by the European Regulation.

Retailer’s awareness survey

During the implementation of the SELINA project, a large period of time was spent in shops carrying out measurements on equipments. This was an opportunity also to gather other types of information. Two other sources of information were exploited: the customers and retailers role in the decision to purchase more energy efficient appliances. These sources represent vital information, to be able to understand the customers’ motivations to choose more energy efficient appliances and the influence of retailers’ advice concerning the energy features of the equipment.

A total of 390 questionnaires were collected and analyzed. These questionnaires were divided into four parts in order to evaluate: the retailer’s advice regarding energy efficiency, customer decision, information about energy information and labels in stores and retailers knowledge of standby & off-mode modes.

The results showed that, despite of retailer’s consciousness of products energy consumption and their energy labels, other types of arguments like, appliance price or functionalities are more frequently used by them to sell a product. Furthermore, the results showed that retailers try to adapt their advice to the customers’ needs (price and product functionalities).

Retailers assume that publishing more information regarding the energy consumption of products and some kind of cost saving calculator/reference would influence the clients to buy more efficient equipments.

Retailers in general show that they have a good knowledge about the presence of low power modes. During the surveys some retailers admitted that sometimes they are “forced” to advise products, not always efficient, because some products are not being sold and to avoid stock problems, leading the clients to buy inefficient products. Another problem revealed by retailers was that sometimes a bonus is given to salesman if they sell specific products chosen by the shops, so the salesmen are led to sell whatever the shop wants them to sell. More exhaustive surveys deserve to be carried out in order to evaluate not only the retailer’s awareness, but also the shops policy towards energy efficiency.

Policies and market transformation

The MURE measure database, which was developed and is continuously updated within the EU-IEE project “ODYSSEE-MURE” (www.mure2.com), shows more than 160 policy measures at the level of the EU and its Member States addressing the electricity consumption of household appliances in the residential sector and of office equipment in the tertiary sector. Almost half of these measures are legislative measures (many of them are the national implementation of the EU measures/regulation), in addition there are some financial and information measures mainly at the national level (see next figure). A similar result can be drawn from the IEA database on energy efficiency measures[4].

[4] http://www.iea.org/textbase/pm/index_effi.asp

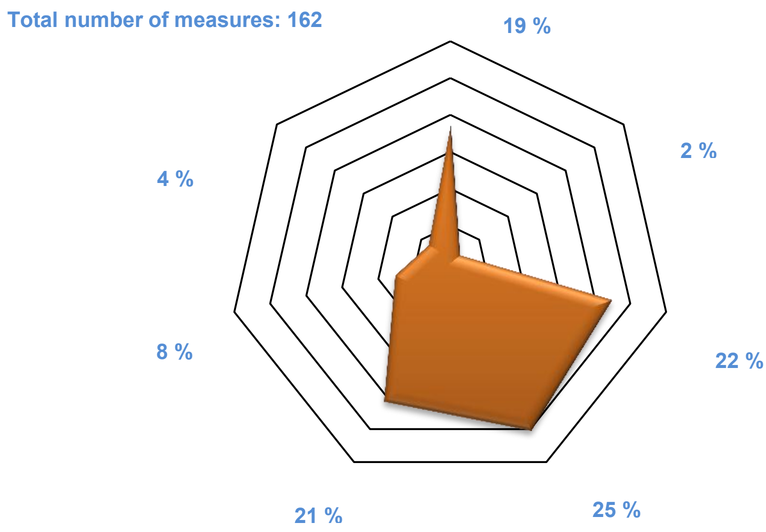


Figure 6. Policy measures addressing energy consumption of residential appliances and office equipment in the tertiary sector (EU, EU Member States, Norway and Croatia).
Source: MURE measure database as of November 2010 (www.mure2.com)

One target of the SELINA project was the collection of specific actions directly addressing consumers and retailers both taking into account actions aiming at the reduction of total energy consumption of the appliances in all operation modes and at standby and off-mode consumption in particular. This includes information and education programmes by energy agencies or other institutions, voluntary activities by retail trade or manufactures, financial support for efficient appliances, additional voluntary labels or the development of information tools for retailers.

The measure collection was based on a common template both including a formal measure description by type of equipment addressed, actor, target group and status, and some detailed on the contents of the measure, the costs and results with regard to energy and standby savings. In the end, more than 100 measures have been collected within the SELINA project by the partners.

The most important measures types are informative and educative measures (61) and financial measures (16). The detailed description of all measures collected for European countries can be found at the project website (www.selina-project.eu) on the specific document with the collection and analysis of the policies and initiatives.

The overview shows that in most countries, information programmes (esp. brochures, leaflets, websites, national labels) are the dominating measure type (also see the next figure). In some countries, however, financial subsidies for very energy-efficient appliances, often paid by an energy utility and not by the government, play an important role, too (e.g. in the Czech Republic or Switzerland). Energy savings are indicated for all measures for which this information is available. In general, the impact of a financial programme is easier to quantify than the single impact of an information campaign, which often serves as an accompanying measure for regulations (labels, minimum efficiency standards) or fiscal and financial measures.

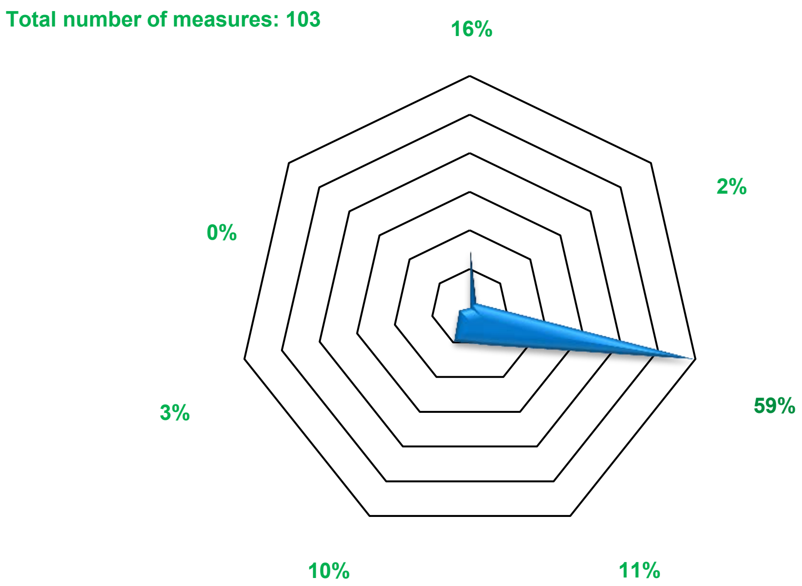


Figure 7. Characterization of the measure types collected in the SELINA project.

Conclusions

The SELINA project developed a common measurement methodology and created extensive data collection of off-mode and standby input power values for more than 6000 different products, allowing for the first time, the collection of a large representative sample of low power mode measurements for the EU market of electrical and electronic appliances in 12 geographically diverse countries. All the data can be accessed through the project website: www.selina-project.eu.

An analysis of the measurement accuracy was performed, showing an average error of about 12%. The standard deviation was also calculated, which has a value of about 20%. This indicates that the measurement method in the shops probably be improved.

It was found that 18.5% of all the measured appliances (including some not in the scope of EC 1275/2008), whose off-mode power was measured, do not respect the EU regulation threshold of 1 W. When the measurements are compared to the 2013 threshold of 0.5 W, the number raises to 41.5%. Regarding standby mode consumption, 31 % of the measured products did not comply with EU regulation limit for the 2010 threshold. When the measured values are compared to the 2013 limit, the numbers of products over the EU regulation target increases to 66 %.

If the appliances not in the EC 1275/2008 scope were removed from the above analysis, a decrease of 4 % for the non-compliant products over standby eco-design 2013 limits was visible. The other values would be affected with differences of less than 0.5 %.

When comparing the 2009 and 2010 measurements, only a slight decrease of the share of appliances exceeding the EU regulation limits was observed.

The results of the retailer’s survey showed that, despite of retailer’s consciousness of the products energy consumption and energy labels, other types of arguments like the appliance price or functionalities are more frequently used to sell a product. This could be due to a lack of information in shops about the equipment energy consumption. Furthermore, the results show that retailers try to adapt their advice to the customers’ needs (price and product functionalities). Retailers in general show that they have a good knowledge about the presence of low power modes. Retailers assume that publishing more information regarding the energy consumption of products and some kind of cost saving calculator/reference would influence the clients to buy more efficient equipments.

The survey on measures enhancing the market transformation towards more energy-efficient electrical appliances showed a wide range of actions and policy tools in the SELINA partner countries.

In most countries, information programmes (particularly brochures, leaflets, websites and national labels) are the dominating measure type. In some countries, however, financial subsidies for very energy-efficient appliances, often paid by an energy utility and not by the government, play an important role, too (e.g. in the Czech Republic or Switzerland). In general, the impact of a financial programme is easier to quantify than the single impact of an information campaign, which often serves as an accompanying measure for regulations (labels, minimum efficiency standards) or fiscal and financial measures. It appears that it is important to keep in mind product changes, like increased network connectivity, which could largely change the low power mode consumption.

The concept of a warning label on products with standby consumption is supported. This appears to be a feasible approach for some products and modes. However, that warning label should not be necessary where there are mandatory requirements such as Minimum Energy Performance Standards (MEPS) that cover relevant products and modes.

It is recognized that equipment connected to networks is of growing importance. It is recommended that increased efforts to compile data and measurements of networked products from a variety of sources in order to obtain better information on networked product characteristics needs to be made.

The new technologies offer many opportunities for energy savings potential but also there are some threats which need to be recognized and understood. There is a strong need to ensure that energy saving paradigms and strategies become a core consideration in all future product designs.

References and Bibliography

[1] **IEA.** IEA (International Energy Agency): Gadgets and Gigawatts. Policies for Energy Efficient Electronics. Paris : OECD/IEA, 2009. online: http://www.iea.org.

[2] **DG TREN, Impact Assessment.** IMPACT ASSESSMENT - Accompanying document to the Commission Regulation implementing Directive 2005/32/EC with regard to ecodesign requirements for standby and off-mode electric power consumption of electrical and electronic household and office equipment. Brussels : s.n., 18/12/2008. SEC(2008) 3071.

[3] **Bertoldi, Paolo and Atanasiu, Bogdan.** Electricity Consumption and Efficiency Trends in the European Union. Institute for Energy, European Commission, Joint Research Centre. s.l. : Luxemburg, 2009. online: http://re.jrc.ec.europa.eu/energyefficiency/publications.htm, ISBN 978-92-79-13614-6.

[4] **EL-TERTIARY.** EL-TERTIARY, Monitoring Electricity Consumption in the Tertiary Sector. s.l. : Intelligent Energy, 2008. D26 - Report on the Project Results.

[5] **REMODECE.** REMODECE - Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe, Final Publishable Report. November 2008. online: remodece.isr.uc.pt.

[6] **Fraunhofer IZM / Fraunhofer ISI.** Fraunhofer Institute for for Reliability and Microintegration (IZM) / Fraunhofer Institute for Systems and Innovation Research (ISI): Abschätzung des Energiebedarfs der weiteren Entwicklung der Informationsgesellschaft. Berlin, Karlsruhe : Study on behalf of the Federal Ministry for Economics and Technology (BMWi), 2009. online: http://www.isi.fraunhofer.de (English summary available).

[7] **EuP Lot6.** Fraunhofer Institute for Reliability and Microintegration (Fraunhofer IZM): EuP Preparatory Studies “Standby and off-mode losses” (TREN / Lot 6), Final Report. October 2007. online: http://www.ecostandby.org.

[8] **Attali, S. et al.** Attali, S., Bush, E., Michel, A., Factors influencing the penetration of energy efficient electrical appliances into national market in Europe. Report for Defra / the Market Transformation Programme by SoWATT and Bush Energie Gmbh. Paris, June 2009 : s.n., 2009.

[9] **Meier, Alan, et al.** Low-Power mode Energy Consumption in California Homes. s.l. : California Energy Commission, PIER Buildings End–Use Energy Efficiency Program, 2007. CEC–500–2008-035.

[10] **Energy Consult.** APP Alignment of National Standby Power Approaches Project: Early Data Outcomes. June 2008.

[11] **Appliance Standby Survey Product Guide.** Detailed Instructions of the International Standby Basket of Products Survey, EnergyConsult with assistance from the SELINA Project, report elaborated for the Department of Climate Change and Energy Efficiency. 2010.

[12] **Gadgets and Gigawatts.** IEA (International Energy Agency): Gadgets and Gigawatts. Policies for Energy Efficient Electronics. Paris : OECD/IEA, 2009. online: http://www.iea.org.

[13] **Attali, S., Bush, E. and Michel, A.** Factors influencing the penetration of energy efficient electrical appliances into national market in Europe. Report for Defra / the Market Transformation Programme by SoWATT and Bush Energie Gmbh. Paris : s.n., June 2009.

[14] **Fraunhofer ISI.** Energy Efficiency Trends of IT Appliances in Households (EU27). Report within the IEE project " Monitoring of Energy Efficiency in EU 27, Norway and Croatia (ODYSSEE-MURE)". Karlsruhe : www.odyssee-indicators.org, September 2009.

[15] **Nordman, B. and Sanchez, M.** Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products, ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove. California : American Council for an Energy Efficient Economy, 2006.

[16] **Gruber, E., Schlomann, B.** The current and future electricity demand of appliances in German households. Paper presented at the EEDAL'06 Conference in London, 21st – 23rd June 2006. 2006.

Acknowledgments

The SELINA Project is mainly supported by the Intelligent Energy Europe Programme of the European Union

All efforts were done to ensure accuracy of the measurements, with appropriate developed methodology and test equipment. Other parties are welcome to provide alternative measurements carried out by a certified institution.

The en.lighten initiative: an approach to the global phase out of inefficient lighting

Gustavo Mañez Gomis, Bernard Jamet, Benoît Lebot, Gerald Strickland, Aurélien Bouayad

1. Introduction

The global demand for electricity is expected to increase dramatically - for lighting alone, electricity consumption is expected to increase by 60 per cent over the next 20 years (IEA, 2006). Electricity for lighting is responsible for 19 per cent of global power consumption and six to eight per cent of global greenhouse gas emissions (GHGs), more than the emissions of Germany and Japan combined. A global market shift from inefficient incandescent bulbs to energy efficient compact fluorescent lamps (CFLs) or LEDs (light-emitting diodes) would cut world lighting energy demand significantly, saving countries and individuals' considerable sums of money in reduced electricity bills. Few actions could cut carbon emissions as cheaply and easily as the phase-out of inefficient lighting, making it one of the most effective and economically advantageous ways to combat climate change.

In 2009, the United Nations Environment Programme (UNEP), in coordination with Philips Lighting and OSRAM GmbH, launched the Global Market Transformation for Efficient Lighting Project known as the en.lighten initiative. The Global Environment Facility (GEF) tasked UNEP to lead this initiative and become the umbrella organization to promote efficient lighting worldwide. The main goal of the initiative is to transform the market to efficient lighting through promoting high performance, energy efficient lighting technologies and phasing out inefficient, incandescent light sources.

The en.lighten initiative brings together international expertise and private sector support to assist developing and emerging countries in the transition to efficient lighting. Multi-stakeholder, expert task forces have been established to; share knowledge and information, provide guidance on the development of policy and regulatory frameworks, addressing technical, quality and sustainability issues.

This article will explore existing barriers to promoting global market transformation towards efficient lighting with an emphasis on developing and emerging countries. This piece will also present the methodology and approaches being used by the en.lighten intiative and its partners in order to generate a global policy consensus to promote a phase out of inefficient lighting technologies in developing and developed countries. The approach and tools used by the en.lighten initiative could serve as a successful and practical model to achieve the phase-out of other obsolete and inefficient electrical appliances on a global scale.

2. The global context of energy efficient lighting

The phase-out of inefficient lighting is considered as one of the most important short-term initiative countries can take to combat climate change created by GHG emissions. According to the IPCC's[1] Fourth Assessment Report released in 2007, global GHG emissions reduction needs to peak no later than 2015 in order to keep the projected global temperature rise under 2°C. In 2003, the supply of artificial light was estimated to result in the consumption of approximately 650 Mtoe of primary energy, which represented 8.9% of total global primary energy consumption. As a result, global lighting-related CO_2 emissions are estimated at 1,900 Mt CO_2, equivalent to approximately 8% of world emissions, or 14% of Annex-I

[1] The Intergovernmental Panel on Climate Change is a UN scientific body tasked to evaluate the risk of climate change caused by human activity.

countries emissions[2]. Therefore, from a climate policy perspective, reducing the energy consumption for lighting by raising the efficiency of lighting systems can be one of the most cost effective means to abate CO_2 emissions (McKinsey, 2007).

The IEA (IEA, 2006) reviewed a large number of sources to produce an estimate of lamp sales by country. As expected, incandescent lamps (ILs) are by far the most commonly sold lamps in the world. They dominate retail lamp sales, primarily in the residential sector, in most countries. It is estimated that roughly 13.2 billion units were sold in 2003 representing over 72% of the global lamp market by volume that year. The United States and China are the largest markets for incandescent lamps, with sales in excess of 2.5 billion lamps in each country. Sales in the rest of Asia and Former Soviet Union countries are estimated at 3.2 billion units and in Europe, at about 1.8 billion.

Table 1: percentages of electricity consumption savings from implementing a shift from ILs to CFLs in selected countries (in %) (en.lighten, 2010)

1.	Cambodia	31
2.	Madagascar	25
3.	Laos	21
4.	Nepal	20.8
5.	Burundi	20
6.	Nigeria	15
7.	Algeria	14
8.	Benin	11.6
9.	Yemen	11.3
10.	Senegal	11
11.	Uganda	10
12.	Guatemala	9.8
13.	Moldova	9.5
14.	Nicaragua	9
15.	Kenya	8.7
16.	Albania	8.3
17.	Kyrgyzstan	8.3
18.	Morocco	8
19.	Syria	8

[2] Figures are from the International Energy Agency's Light's Labour's Lost (2006).

20.	Cote d'Ivoire	8

According to estimates developed by the en.lighten initiative (2010) by simply replacing ILs with CFLs:

- 409 TWh per year would be saved, accounting for 2.3% of the global electricity consumption. By way of comparison, this scale of replacement would save electricity to 136 medium sized coal-fired power plants of 500 MW each.
- 246 Million tons of CO_2 reduction will be achieved on a global scale, which is greater than combined emissions of the Netherlands and Portugal. 246 Mt CO_2 per year equals to approximately 62 million mid-size cars.

The estimates show that in Africa, a country such as Nigeria could cut its electricity consumption by over 15 per cent in a switch to energy efficient lighting while reducing CO_2 emissions from fuel combustion by close to 5%. In Asia, a country like Cambodia could save over 30 % of its electricity consumption while reducing CO_2 emissions by more than 13 %. In Uzbekistan, electricity consumption saving could be over 20 %; in Croatia, nearly 10 %; in Guatemala also close to 10 % and in Yemen just over 10 %[3].

Table 2: percentages of CO_2 emission reductions from fuel combustion electricity consumption savings from implementing a shift from ILs to CFLs in selected countries (in %) (en.lighten, 2010)

1.	Laos	14.3
2.	Cambodia	13.6
3.	Uganda	10
4.	Burundi	5
5.	El Salvador	4.8
6.	Senegal	4.8
7.	Lebanon	4.4
8.	Haiti	4.3
9.	Guatemala	4.3
10.	Botswana	4.2
11.	Cote d'Ivoire	3.9
12.	Sri Lanka	3.9
13.	Benin	3.2

[3] Multi-billion dollar benefits of global switch to energy-efficient lighting, UNEP, 1 December 2010

14.	Morocco	3.2
15.	Kosovo	2.9
16.	Algeria	2.9
17.	Moldova	2.7
18.	Kenya	2.6
19.	Jordan	2.6
20.	Honduras	2.4

3. Efficient lighting and development

By phasing out ILs, peak power demand and black-outs in a large number of developing countries could be substantially reduced, making electricity available for other uses and helping to ensure energy security. When considering both aspects of the cost benefits – energy savings and saved investments – the transition to energy efficient lighting technologies is financially one of the most attractive projects worldwide, and the "lowest hanging fruit" when it comes to energy efficiency initiatives.

In light of the investments needed to construct new power plants, supporting integrated approaches towards efficient lighting in developing countries with increasing energy demand could save millions of dollars. In South Africa where the gap between electricity supply and demand has created a number of black outs, this issue was addressed by the free distribution of about 43 million compact fluorescent lamps (CFLs) to low income populations between 2004 and 2010, as part of Eskom's efficient lighting programme [4].

The en.lighten country lighting assessments estimated that by shifting from ILs to CFLs, the world could save 136 coal-fired power plants, resulting in avoided investment costs of approximately 113 billion US$, exceeding the cost savings for energy by a factor of 2.4. For non-Annex I countries (developing and emerging economies) this saved investments would amount to 43 billion US$.

And ILs are just one part of inefficient lighting technologies - The elimination of less efficient linear fluorescent lamps in industrial and commercial lighting applications, as well as mercury lamps used in street lighting, would also contribute significantly to energy savings and CO_2 emission reduction.

4. Barriers to the uptake of efficient lighting technologies

As it has been explained above CFLs are energy-efficient and financially cost-effective, yet a wide number of barriers have been identified to promoting the adoption of efficient lighting technologies. Some of them are identified in this section:

Consumer preferences

Changing consumer habits and perceptions is one of the most challenging aspects to address. Some consumers also are skeptic about the perceived benefits of lighting technologies, and are therefore, inclined to continue to use the technologies that they are familiar with. Although CFLs have greatly improved in recent years with a number of technical issues (color, warmth, delayed start, flickering) having been addressed, overall product quality is still a large problem.

[4] Personal Communication, National Energy Efficiency Agency of South Africa

Quality issues

The situation may be more complicated in developing countries where unpleasant experiences with low quality CFL bulbs that have flooded the market have discouraged customers. A study developed by ECO Asia in 2007 reported that approximately half of the CFLs produced in Asia could be considered of questionable quality (for 2006 and 2007). In 2010, this amount decreased to one third (ECO-Asia April 2010). This creates a negative experience for consumers and affects the success of governmental efforts to implement efficient lighting policies and projects. The same would be applicable for internationally supported projects. Ensuring the quality of CFLs through appropriate testing and certification mechanisms can assist in building trust among consumers.

Barriers related to lack of awareness and high initial costs of efficient lighting

The lack of awareness about the energy and financial savings of efficient lamps is a key deterrent for the penetration of these products in many developing countries. Most consumers are unaware of the high operating costs of incandescent bulbs which are not shown on their electricity bills and they are unlikely to invest in more efficient alternatives with a higher initial cost. This, compounded with their high initial cost when compared with inefficient technologies (ILs), creates a distinct barrier hampering the market penetration of CFLs in many developing countries. Public campaigns, awareness raising activities, subsidies and promotional mechanisms act as effective tools to respond to this challenge.

Split incentives

Those who make decisions about lighting equipment may not necessarily be the ones who pay directly for the system's energy use and thus, lack incentive to invest in energy efficiency equipment which would benefit the resident or renter. In addition, public purchasers responsible for choosing and maintaining public lighting are often not responsible for purchasing decisions. The high initial construction or renovation costs s needed to install efficient lighting solutions are often a deterrent to public authorities with limited budgets, even if the environmental and economic benefits have been understood[5].

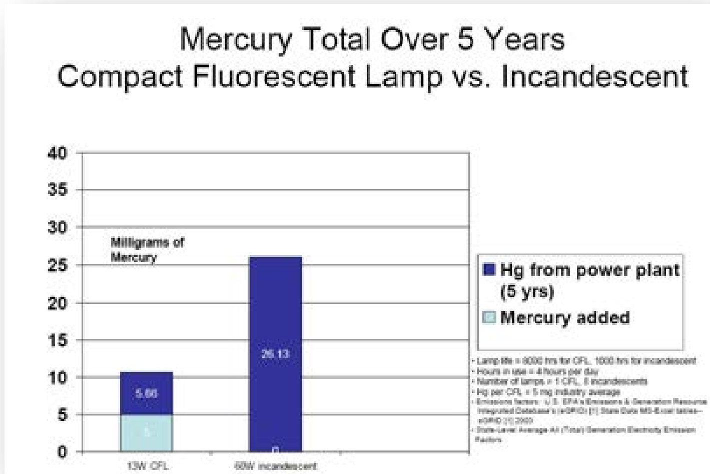
Environmental and health risk perception

Concerns over the risk of the mercury content of CFLs with regard to health and the environment are widespread. However, a CFL has an average content of less than 4 milligrams, much less than the content produced by the carbon combustion needed to light a single incandescent lamp (see figure 1). It is important to limit the content of mercury in lamps to the very minimum allowable dose. The European RoHS Directive provides a best practice example in this sense. In addition, it is important to share information and guidance on what steps to take in case of breakage (the US EPA, manufactures and other regional and national authorities have developed good materials to inform consumers).

A growing number of countries have already or are planning to implement collection and recycling programs for the recovery and sound end-of-life treatment of these lamps to ensure that the mercury is not released into the environment (European Union, South Africa, Philippines, Colombia, etc). A number of concerns have been raised regarding the effectiveness of these approaches for example, in the European Union, where the collection rates vary significantly between Scandinavian and Mediterranean countries. This also applies to other hazardous wastes and should not be a deterrent to the introduction of these systems. In light of the global efforts to develop a legally binding treaty to limit mercury, countries should explore the implementation of appropriate systems which coincide with their national circumstances.

5 European Lam Companies Federation, 2007. Make the Switch. The ELC Road Map for Deploying Energy Efficient Lighting Technology Across Europe

Figure 1: Calculation of Total Mercury Emissions arising from CFLs and ILs (National Electrical Manufacturers Association, 2008)



In conclusion, energy-efficient lamps are economical, commercially viable and technologically available, but due to several barriers, they have not reached the market penetration rate that they could for simple economic reasons. It is therefore, necessary to ensure some degree of market intervention at both national and international levels. A number of countries have already taken action in this sense, providing a wealth of information to other countries interested in promoting efficient lighting.

5. Global moves to phase-out of inefficient lighting

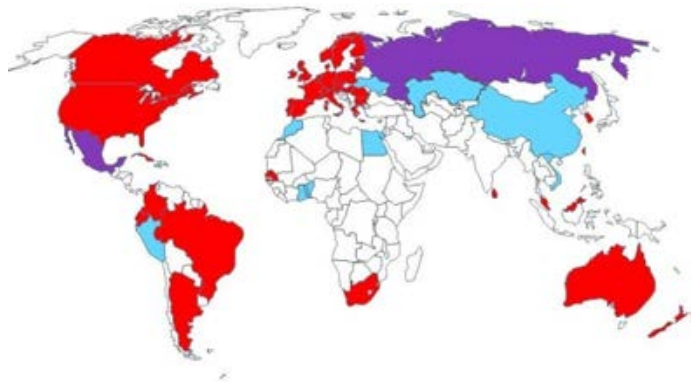
A great number of international and regional initiatives for to promote efficient lighting and develop phase-out schemes have been implemented or are currently under development. The European Union and most OECD countries, including the US, Canada and Australia have already established a staged approach to phase-out out inefficient lamps by using mainly regulatory, and in some cases additional voluntary measures. In Australia, an import restriction on inefficient incandescent light bulbs used for general lighting purposes, was introduced as early as 2007.

In Latin America, Cuba was the first country to implement regulatory measures to phase-out incandescent lamps (2005). Since then, other countries have followed suit or will do so in the near future including; Argentina (2010), Ecuador (2011), Brazil, Mexico and Colombia (2012).

In most of the cases the preferred approach in the regulatory phase outs has been to restrict the supply of inefficient lamps through the establishment of minimum performance limits. Lamps that do not meet the requirements established are not allowed in the market. Cuba followed a different route and enacted an outright technology ban on incandescent lamps.

A long list of developing and emerging countries including China, Indonesia, Vietnam, India, South Africa, Thailand and the Philippines have set up promotional and in some cases free give away programs for CFLs (e.g. Vietnam, South Africa, China) or distributed them at a considerably lower price (e.g. India). Some of these countries are now discussing the implementation of planning regulatory phase-outs to lock in the benefits of promotional programs (China, South Africa, Philippines and Vietnam). Sri Lanka, Taiwan and Malaysia decided to phase-out incandescent lamps from their markets using regulatory means.

Figure 2: Countries with enacted phase out legislation and countries implementing national projects with GEF support promoting efficient lighting



- Country with enacted phase-out legislation
- Country hosting a GEF efficient lighting projects
- Country hosting a GEF funded project and with enacted phase-out legislation

It is expected that China, with the support of the GEF and UNDP will release in the coming months a policy roadmap to phase out incandescent lamps. As the largest manufacturer of incandescent lamps the potential effects that this will have could have consequences in the rest of the world, especially if China decides to phase out not only the production for internal consumption but also for international export. Such ambitious move would put the world in an excellent route towards achieving efficient lighting. Yet, a coordinated approach would be needed to ensure that new countries do not take on the production of inefficient incandescent lamps.

6. Bulk procurement and CFL give-away programs

A number of countries have used bulk procurement initiatives in order to fasten the penetration of efficient lighting technologies. The benefit of this type of program includes the swift reduction of peak load demand as well as serving to familiarize citizens with efficient lighting technologies. In countries with a constant increase of energy demand, it is highly profitable for utilities to invest in CFLs to reduce the peaking demand due to the high investment cost of a power plant.

Through bulk procurement, the price of lamps is lowered making them less expensive than though normal market channels. Another positive aspect is that if handled properly and with the sufficient product quality and product monitoring safeguards, the program could contribute to ensure the supply of good quality products in a given country.

It is important to bear in mind that these programs can significantly hamper the markets where there are decent established retailers, as they limit traditional market channels for the distribution of lamps. There is a growing consensus that give-away programs should be utilized hand-in-hand with other policy and regulatory approaches in order to ensure their sustainability and to lock in energy savings for the long term. If bulk programs are not followed by regulatory initiatives, once the free lamps are exhausted, there are high chances consumers will be tempted to return to the use of inefficient lighting eliminating the possible.

The use of carbon credits in promotional activities

The CDM is one of the three market-based, flexible mechanisms under the Kyoto Protocol to help countries meet their emission targets, and to encourage the private sector and developing countries to contribute to emission reduction efforts. It allows emission-reduction (or emission removal) projects in developing countries (non-Annex I countries that do not have an emissions reduction target under the Kyoto Protocol) to earn certified emission reduction (CER) credits that can be traded and sold. A total of 14 efficient lighting projects have been approved by the UNFCCC[6], 11 of which in India, and 31 are waiting for validation (including a few off-grid lighting projects)[7] [8]. The projects consist on mostly utility and promotional programs where CFLs are sold at a considerably lower price, as well as free give-away initiatives, aiming to increase the efficient use of electricity through the replacement of traditional incandescent light bulbs with CFLs, thereby reducing CO_2 emissions.

The UNFCCC adopted in November 2010 a new methodology for demand-side activities for efficient lighting technologies[9].This new methodology was developed to address the monitoring issues encountered with a previous methodology [10] and to allow simpler approval of identical small-scale projects, it is expected this new approach may trigger the development of new and additional CDM projects. The UNFCCC has also recently developed a methodology for off-grid lighting[11], leading to the registration of three projects in India and one in Morocco.

Whereas CDM projects are a useful mechanism to support in transition to efficient lighting – the carbon credits that can be obtained can be worth more than the entire program cost – the main difficulties encountered when embarking in the implementation of these projects include (i) the lengthy process to develop and approve the proposal and the delay in obtaining carbon credits (ii) the resources and technical capacities needed to develop a proposal (iii) the instability of grid, (iv) the risks associated with local consumer behavior, (v) and the complex monitoring mechanism. Another issue of importance to consider in the implementation of CDM lighting projects is the additionality principle, which refers to the causality between international financial support for an activity and the extent to which the activity would have happened in the absence of such support (Streck, 2009). If a phase out of incandescent lamps has been implemented in a country, the whole difficulty to demonstrate the additionality of a CFL give-away, utility or promotional project is to prove that, had not this project been implemented, the demand for efficient lighting products would be compromised or undermined. The CDM rules seek to guard against the mechanism becoming a perverse incentive for developing countries to avoid promulgating climate-friendly national policy. Yet, due to the difficulty of proving this, a clear risk exists that national officials may not be interested in promoting regulatory approaches to phase out in order to reap the benefits of CDM projects.

7. Internationally supported initiatives and the role of the Global Environment Facility

The Global Environment Facility (GEF) stands as one of the most active bodies promoting the transition to efficient lighting in developing and emerging countries. Established in 1991, the GEF is the largest

---

6 As of April 2011. For more detailed information, see the database developed by the IGES available at the following link: http://www.iges.or.jp/en/cdm/report_cdm.html

7 http://cdm.unfccc.int/Projects/projsearch.html

8 http://cdmpipeline.org/cdm-projects-type.htm

9 http://cdm.unfccc.int/filestorage/9/J/A/9JASTI0QYD24GWVZLRF16UK7HOX8B3/EB54_repan06_AMS-II.J_ver04_0406.pdf?t=Yzd8MTMwNDU5NzA2Ny45Nw==|55Qyt_PCmgcacyVVWo0vo6oHFEc=

10 http://cdm.unfccc.int/filestorage/S/6/K/S6KJMZ0A7UON324I5QHER8BTPLDFCX/EB48_repan16_AMS_II.C_ver13.pdf?t=S1B8MTMwMzg5NzMwNS4yNQ==|PSPeuwee2fi_XUG6m0APkgQWUF8=

11 http://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf#AMS-I.A.

public funder of projects to improve the global environment today. Over the last years the GEF has supported the efforts of a wide range of countries in the promotion of energy efficiency lighting. A total of 40 GEF country projects have been approved or will be endorsed in the coming months that address energy efficient lighting which are supported primarily by three GEF implementing agencies. The World Bank is supporting Haiti, Mexico and Togo in their efforts to move to efficient lighting; UNDP is providing support to China, Ukraine, Russia, Egypt and Kazakhstan and Nigeria. UNEP, with the support of GEF, is providing support for the phase out incandescent lamps with Vietnam, Peru, Morocco and soon in Cote d'Ivoire.

A common objective for many of these national projects is the progressive phase-out of incandescent lamps by restricting the supply of inefficient lighting products through policy, legal measures and by promoting the demand for energy efficient lighting products. This can be achieved by; the improvement of efficient lighting standards and policy frameworks (for example in China, Russia, Vietnam, Nigeria, Kazakhstan), the transformation of the local lighting production market (i.e. China, Vietnam), or as the result of consumer awareness campaigns and give-away programs (Togo).

8. The need for a global integrated approach to promote efficient lighting

The en.lighten initiative was created by the GEF and UNEP as a public private partnership in collaboration with Philips Lighting and OSRAM to assist developing and emerging countries move faster in realizing the potential of efficient lighting. Established to become an umbrella initiative in support of existing and future efficient lighting projects, en.lighten is supported by a multi-stakeholder structure encompassing lighting experts and stakeholders from diverse sectors from the North and South. The initiative develops recommendations and guidance that countries could adopt in order to effectively and efficiently transform their markets without repeating the mistakes made by 'first movers'.

Over 40 organizations including; governments, the private sector, civil society and international organizations, have been brought together through four taskforces to compile international best practices and develop recommendations. The recommendations that will be generated from the various groups of experts will follow an integrated approach to address all possible lighting issues a country may face when promoting efficient lighting. These issues will range from; how to calculate the benefits of efficient lighting, to monitoring the effectiveness of the implementation of market transformation efforts; establishing performance and testing standards, or the implementation of end-of- life approaches for spent lamps.

Table 3: roles of the en.lighten multi-stakeholder taskforces

Policy, Regulation and Finance Taskforce	The Policy Regulation and Finance Taskforce makes recommendations for the development of policies, regulations, norms and financial incentives necessary to overcome barriers to efficient lighting. It consists of 3 sub-groups: *Test standards sub-group* has been established to measure performance standards. Its primary task is to submit proposals to harmonize international test methods allowing for regional variations such as; excessive temperature, humidity and unstable power supplies. This sub-group will also ensure a process of mutual recognition for test labs. *Minimum energy performance and quality requirements sub-group* is responsible for the establishment of energy performance and light quality requirements based on international standards. Its mandate covers performance and light quality issues such as; lifetime, efficacy and lumen maintenance, colour matching and Colour Rendering Index (CRI), voltage sensitivity, power factor and harmonics and mercury content. Guidelines for national standards will be established to ensure that quality products are available to all

	income groups. *Monitoring, verification and enforcement sub-group* provides recommendations so products complying with relevant international and national legislation are made available. This will include issuing guidelines for monitoring mechanisms, such as; registration and enforcement mechanisms.
Consumer, Environmental Protection and Recycling Taskforce	This group reviews scientific and develops science-based recommendations on lifecycle issues; environmental, health and safety aspects; and general consumer concerns regarding lighting including the use of mercury, recycling and end-of-life treatment options.
Country Lighting Assessments, Market Data and Analysis Taskforce	This group reviews country and global lighting data; and, estimates the energy, CO_2 and financial savings associated with a move to efficient lighting.
The Off-Grid Lighting Taskforce	The group works on the definition of an effective product quality assurance strategy for OGL products and avenues to ensure that resulting product quality approaches are enforced. The taskforce will review best practices to minimize impacts on the environment and human health associated with the lifecycle of products. The taskforce will make recommendations on an approach to regulate OGL in order to address regulatory and policy barriers suppressing its development.

Currently, the initiative is focused on the development of a global roadmap for efficient lighting market transformation as well as policy and technical guidance for countries on how to transform their markets to efficient lighting. The outcomes will be shared and discussed extensively at upcoming meetings with national and regional stakeholders which are planned for the second half of 2011. The initiative will seek the endorsement and implementation of its recommendations in as many countries as possible via a "sign in" mechanism which is currently under development.

The en.lighten initiative is expected to deliver the following key outcomes in order to assist countries interested in promoting an effective transition to efficient lighting:

- *A roadmap* for global lighting market transformation providing recommendations to phase-out obsolete lighting technologies and the introduction of new energy efficient replacements. The roadmap will be presented and discussed among a broad range of governments and stakeholders worldwide as a global strategy to phase out inefficient lighting.

- *A set of global harmonized guidelines* for quality, performance-based standards, and certification procedures for energy-efficient lighting products.

- *A comprehensive tool kit* to promote market transformation on a national level, based on examples of countries' best practices. The toolkit will be addressed to support government officials, the private sector and civil society for various lighting related topics including: policy and standards development, certification, verification, communication programs, utilizing financial mechanisms to promote the transition to efficient lighting, consumer and environmental protection, collection and recycling systems, etc.

- *Country Lighting Assessments* developed for developing and emerging countries providing key information including; technology options, economic savings and GHG reductions potential that would result from the implementation of an efficient lighting program.

- Support for national and regional *strategies and policies* for efficient lighting in selected countries.

9. Conclusion

Evidence shows that the global transition to efficient lighting is progressing with voluntary and mandatory market transformation programs implemented in over 60 countries[12]. Phasing out of inefficient lighting technologies will be soon in place in an increasing number of developing and emerging countries. en.lighten intends to highlight the best practice examples to incentivize the almost 100 nations which do not yet have effective plans to promote a transition to efficient lighting an reap its climate, energy and financial benefits. A wide range of practices and experiences are available to effectively and efficiently transform national markets to efficient lighting, those countries which have not done it yet do not need to repeat the mistakes made by ‘first movers’. This approach presents an opportunity to ensure that areas usually overlooked in the *national resolve* to phase out inefficient lighting such as the formulation of necessary standards, environmental sustainability considerations and compliance and testing for quality programs are given the right level of consideration and hence the best chance of implementation.

A global consensus to phase out inefficient technologies would pave the way to lock in the benefits of efficient lighting and avoid that developing countries become the dumping grounds for obsolete lighting technologies. It is expected that the en.lighten initiative will generate the consensus needed to achieve this move.

Bibliography

[1] Global Market Transformation for Efficient Lighting – Project Document, UNEP/GEF, 2008 Project

[2] Light’s Labour’s Lost, International Energy Agency, 2006

[3] Make the Switch. The ELC Road Map for Deploying Energy Efficient Lighting Technology Across Europe, European Lam Companies Federation, 2007

[4] An introduction to Phase-out Schemes for Inefficient Lighting, 2008

[5] Fourth Assessment Report, International Panel on Climate Change, 2007

[6] Large-Scale Residential Energy Efficiency Programs Based on Compact Fluorescent Lamps (CFLs). Approaches, Design Issues, and Lessons Learned, World Bank, 2009

[7] A Cost Curve for Greenhouse Gas Reduction. The McKinsey Quarterly, 2007

[8] The Concept of Additionality under the UNFCCC and the Kyoto Protocol: Implications for Environmental Integrity and Equity, Charlotte Streck,

[9] USAID, Phasing in Quality. Harmonization of CFLs to Help Asia Address Climate Change, March 2009

[10] USAID, Testing for Quality. Benchmarking Energy-Saving Lamps in Asia, April 2010.

[12] http://www.enlighten-initiative.org/CountryLightingAssessments/MapoftheCountryLightingAssessments/tabid/29417/Default.aspx

Annex I **– List of organizations contributing in the en.lighten Taskforces**

Sector	Organization
Private Sector	Chinese Association of Lighting Industries (CALI)
	ELCOMA
	Osram GmbH
	Philips Lighting
Civil Society	Clinton Climate Initiative (CCI)
	Zero Mercury Working Group (ZMWG)
	European Environmental Citizens Organization for Standardization (ECOS)
	Natural Resources Defense Council (NRDC)
	The Energy and Resources Institute (TERI)
	World Bank
	WWF China
	Zero Mercury Working Group (ZMWG)
Governments	Department of Climate Change and Energy Efficiency, Australia Department of Environment and Natural Resources of the Philippines Ecoasia/USAID
	European Commission DG Energy
	European Environmental Bureau (EEB)
	GIZ, Germany
	Indian Bureau on Energy Efficiency (BEE)
	Ministry of Environment and Forests, India
	Ministry of Environmental Protection, China
	Ministry of Industry, Cuba
	Ministry of the Environment, Brazil
	Ministry of the Environment, Japan
	National Energy Efficiency Agency, South Africa
	National Lighting Test Centre (NLTC), China
	Philippines Department of Energy
	Swedish Energy Agency (STEM)
	U.S. Department of Energy
	U.S. EPA
	UK DEFRA
International Organizations	Asian Development Bank
	International Electrotechnical Commission (IEC)
	International Finance Corporation
	United Nations Environment Program United Nations Development Program
Other	Laplace, Université Paul Sabatier, Toulouse PILESLAMP-Project Management Office, China

Laboratory and field measurements of the power factor and the harmonic emission from energy-efficient lamps

Sarah K. Rönnberg[(1)], Math H.J. Bollen[(1,2)], Mats Wahlberg[(1,3)]

[(1)]Luleå University of Technology, Power Engineering Group, Skellefteå, Sweden

[(2)]STRI AB, Gothenburg, Sweden

[(3)] Skellefteå Kraft Elnät AB, Skellefteå, Sweden

Abstract

This paper presents the results of a set of measurements to quantify the impact of energy-efficient lamps on the power system, especially on the distortion of the current waveform. The first set of measurements was performed in the laboratory, where a full-scale electric model of a detached house was equipped with the standard domestic equipment including incandescent lamps. A domestic user pattern was defined based on combinations of equipment switched on and off at predefined instants. The second set of measurements was performed with a medium-size hotel. The measurements show that the replacement of incandescent lamps by LED lamps and CFL's results in some increase of the distortion of the current waveform, as expected, but that there is no reason for concern. The presence of other equipment, like a heat pump or a dish washer, impacts the current waveform much more than the replacement of the lamps. It is also encouraging that no increase in distortion is observed in the most realistic experiment (with the hotel).

Introduction

With the interest to reduce electrical energy consumption there is an upcoming shift from the traditional incandescent lamps to more energy efficient types of lighting. The most common replacements for incandescent lamps are compact fluorescent lamps (CFL). The next stage will be the replacement by lamps based on light-emitting diodes (LED's). This ongoing replacement has raised the concern of a possible adverse effect on the power grid as a resistive load is replaced with an electronic one. The main concerns include the distortion of the current and voltage waveform, losses in the grid, and the angle between voltage and current waveform as quantified through the so-called displacement power factor (cos φ). [1]. The waveform distortion of the current from individual lamps is studied among others in [2][3]. The impact on the voltage distortion of a massive replacement of incandescent lamps by CFL is studied in [4]. A limited increase in emission per building is predicted in [2], whereas [4] predicts a large increase in voltage distortion. The latter is however based on simulations, where the cancellation of the distortion between different types of loads is only partly included.

The study presented in this paper is completely based on measurements. Two experiments have been conducted in which the current distortion of an installation is measured before and after the replacement of all incandescent lamps by energy-saving lamps. The two experiments are described in the forthcoming two sections. After the description of the experiments, the paper continues with a presentation of the results, where a distinction is made based on the different ways in which individual equipment impacts the current of the total installation. The paper also includes an estimation of the strength of the power system needed to maintain voltage distortion within the limits for the observed current distortion.

Experiment 1: Domestic Customer

A full-scale electrical model of a detached house was built in the Pehr Högström laboratory at Luleå University of Technology, Skellefteå, Sweden. The model has realistic cable length and cable areas for an urban residential home in Sweden [5].

The pattern used to represent the variations in consumption, is shown in Table I, where each column represents a three-minute period and each row a part of the load that was switched separately. The time stamps in the upper row indicate the end of the period. Details of the loads are given in Table II and below:

With the exception of the computer and the television, all loads used a certain operating cycle that could not be controlled. The power consumption and harmonic emission from this equipment may therefore not be identical between different scenarios. All LED lamps were 7 W and all CFL's were 11 W, unless otherwise indicated in the table. All CFL and LED lamps had a power factor of 0.6.

Table I. Load switching pattern used during the experiments.

	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108
Lamps A			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Lamps B					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X				
Lamps C													X	X	X	X	X			X	X	X	X													
Computer and television									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
Microwave												X	X											X	X											
Dishwasher						X	X	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X					
Induction Stove							X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X						
Heat pump	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		
Refrigerator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table II. Details of the lighting load used for the four scenarios

	"past"	"present"	"future"	"far-future"
Lamps A	12 60-W incandescent	4 halogen + 4 60-W incandescent + 4 CFL	6 LED + 6 CFL	12 LED
Lamps B	18 60-W incandescent	6 halogen + 6 60-W incandescent + 6 CFL	9 LED + 9 CFL	18 LED
Lamps C	2 dimmable 60 W incandescent	2 dimmable 20-W CFL	2 dimmable 20-W CFL	2 dimmable LED
Total	1920 Watt	1150 Watt	310 Watt	224 Watt

A number of different scenarios were tested; all give equal light output in Lumen. Normal household equipment was connected in the house in addition to the lamps. The normal household equipment was kept the same for the five scenarios: the only difference was the lighting. The load was changed in three-minute intervals with a total pattern of 108 minutes, 54 minutes with a heat-pump and 54 minutes mirroring the same pattern without the pump. The pattern was designed so that both high load (morning and afternoon) and low load (night) was simulated. The aim of the pattern was not to reproduce a typical day, but to include a range of combinations of load types. The voltage and current were measured at the delivery point, covering the complete load.

Experiment 2: field measurements with a hotel

Measurements have also been performed on a medium-sized (76 rooms) hotel in the North of Sweden. During the start of the measurements, the majority of lighting used in the hotel consisted of incandescent lamps. All incandescent lamps were replaced by energy saving lamps, both CFL and LED, with a typical power-factor of 0.5 – 0.6. Measurements were performed before, during and after the replacement. A Dranetz Power Visa monitor was used to obtain the harmonic distortion and several other parameters over each 10-minute interval.

Before the change, the lighting in the hotel consisted of 447 incandescent 40-W lamps with E27 fitting and 116 incandescent 40-W lamps with E14 fittings. The E27 lamps have been replaced by 7-W LED lamps and the E14 lamps by 8-W CFLs. A total of about 30 lamps were replaced in the common areas of the hotels; the others were replaced in the guest rooms. In total this would give a reduction in active power up to 18 kW.

Three measurement series have been conducted: before the replacement (26 March – 9 April 2009), during the replacement (13 – 29 April 2009) and after the replacement (4 – 19 May 2009).

In the forthcoming sections, we will refer to the results from Experiment 1 as the "domestic customer" and to the results from Experiment 2 as the "hotel".

Active Power

The active power for the domestic customer is shown in Fig. 1. The switching pattern is clearly visible as well as the reduction in active power due to the replacement of the incandescent lamps.

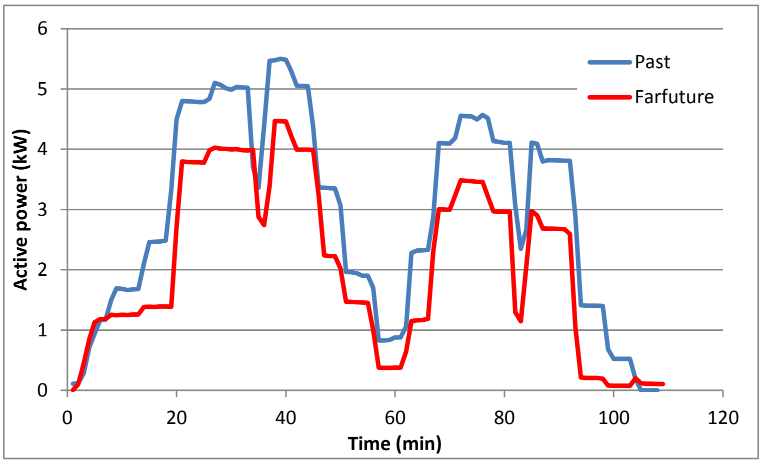


Fig. 1. Active power for the domestic customer as a function of time: two scenarios.

The active power of the hotel also showed a reduction after the replacement compared with before the replacement. This reduction was not as clear as in the controlled experiment for the domestic customer. The active-power consumption depends among others on the number of rooms occupied. To illustrate this, the daily energy-consumption (noon to noon) is shown in Fig. 2 versus the number of rooms occupied, before and after the replacement. The energy consumption is clearly lower after than before the replacement.

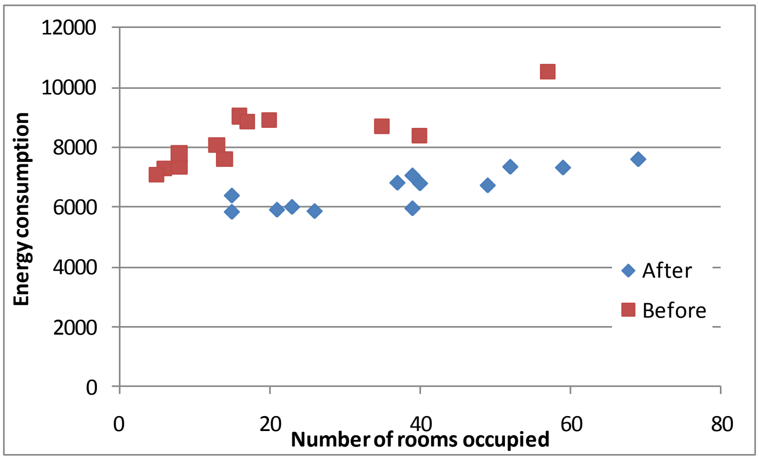


Fig. 2. Relation between daily energy consumption with the hotel (in arbitrary units) and the number of rooms occupied.

Harmonic Emission

The third harmonic versus time for the domestic customer is shown in Fig. 3. The variations versus time are similar for harmonics 5 and 7. The overall pattern does not change despite the replacement of all incandescent lights first by compact fluorescent lamps and next by LED lights. For all three harmonics (3, 5 and 7) are the values significantly higher during the first half of the measurement than during the second half. This is most likely due to the presence of the heat pump during the first half. The replacement of the incandescent lights does result in some increase in the harmonic distortion, especially for the “future” scenario. The increase is however of limited size and smaller than for example the impact of the microwave.

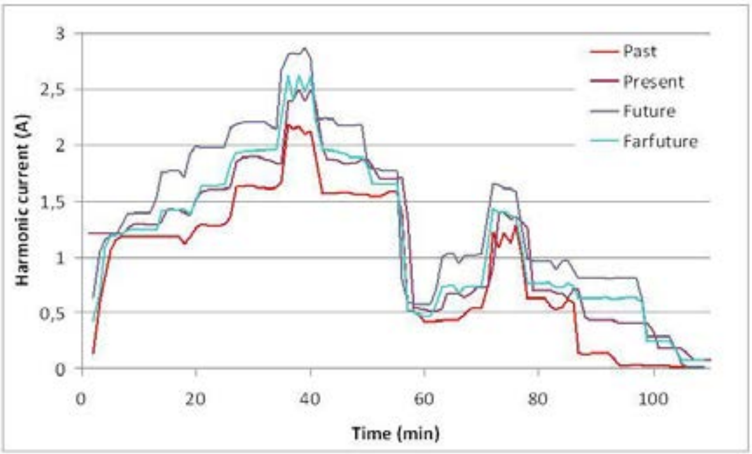


Fig. 3. Third harmonic current for the domestic customer as a function of time

The change in harmonic emission is quantified in Table 3: the 95, 99, and 100% values of the third, fifth and seventh harmonic current are shown for the four scenarios. The relative increase (last row in the table) in the Far Future scenario compared to the Past scenario is about 20% for the third harmonic, about 25% for the fifth harmonic and about 40% for the seventh harmonic.

Table 3. High-percentile values of the harmonic emission from the domestic customer

	Harmonic 3			Harmonic 5			Harmonic 7		
	95%	99%	100%	95%	99%	100%	95%	99%	100%
Past	1.82 A	2.17 A	2.19 A	0.79 A	0.81 A	0.82 A	0.33 A	0.36 A	0.36 A
Present	2.18 A	2.49 A	2.50 A	0.80 A	0.84 A	0.84 A	0.42 A	0.44 A	0.44 A
Future	2.51 A	2.82 A	2.87 A	1.01 A	1.07 A	1.07 A	0.54 A	0.55 A	0.55 A
Far Future	2.23 A	2.62 A	2.62 A	0.98 A	1.00 A	1.08 A	0.47 A	0.49 A	0.49 A
Relative increase	23%	21%	20%	24%	27%	32%	42%	36%	36%

The increase of the seventh harmonic could be some cause for concern. The emission starts however from a rather low value, so that this large relative increase might not pose a concern for the network.

The variation with time for the different harmonics in the supply current to the hotel is determined by many other factors than only the replacement of the lamps. There is no obvious trend visible in the harmonic levels for any of the harmonics. This is illustrated in Fig. 4 for the third harmonic: the levels before during and after the replacement are very similar; the day-by-day variations are bigger than the variations between the three periods (before, during and after the replacement).

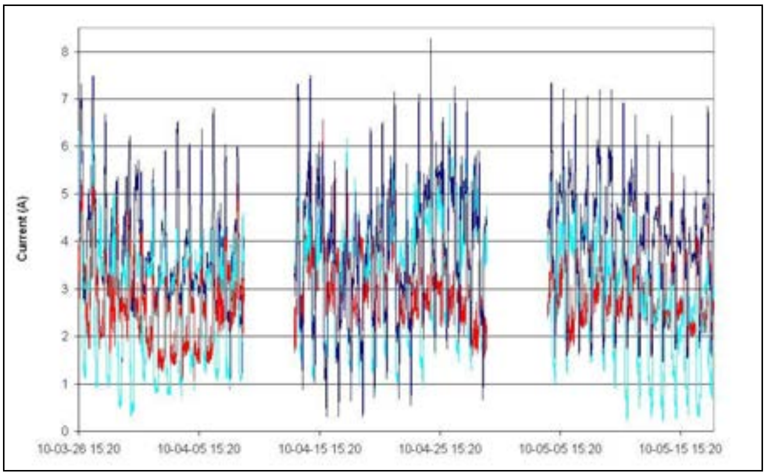


Fig. 4. Third harmonic for the hotel during the whole measurement period

The 95% values of the third, fifth and seventh harmonic for each phase before and after the replacement are shown in Fig. 5. It shows an increase in third harmonic in two of the phases and a decrease in the third phase. The changes in third harmonic are minor however: -3%; +5% and +2%. We conclude that there is no observable difference in the third harmonic current due to the replacement.

The fifth harmonic current shows an increase in two of the phases, with the increase being about 40% in phase A. The third phase does show a decrease in harmonic current however. The increase is biggest in the 95% value; the increase in 99% value is only 15%. It should also be noted that the maximum rms current is over 150 A; the fifth harmonic current after replacement is thus still less than 3% of the rated current. The seventh harmonic goes down in two phases and remains about the same in the third phase. The increase in seventh harmonic current, observed for the domestic customer, is not visible with the hotel at all.

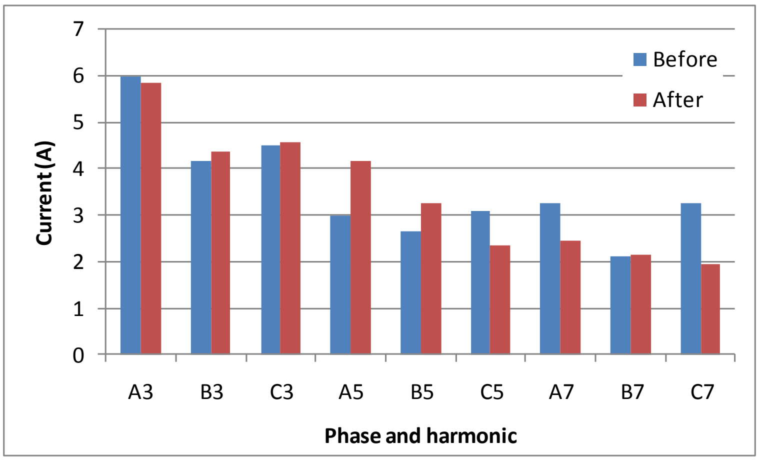


Fig. 5. 95% values of the third, fifth and seventh harmonic with the hotel before and after the replacement.

The harmonic spectrum has been calculated from the 99-percentile of the individual harmonics. The results for the domestic customer are shown in Fig. 6 for the “Past”, “Future”, and “Far Future” scenarios. The lower limit of the vertical axis is slightly above the resolution of the measurements. The even harmonics (lower row of points) do not show any significant increase; whereas also most of the odd harmonics (upper row of points) show only minor changes. Significant increase is only visible for harmonics 9, 13, 19, 21, 23 and 25.

Note that the emission for the Far Future scenario (with only one type of lamp) is higher than for the Future scenario (with two types of lamps: CFL and LED’s) for harmonics 13, 19, 21 and 23. A possible explanation is the cancellation between the two lamp types for these harmonic frequencies.

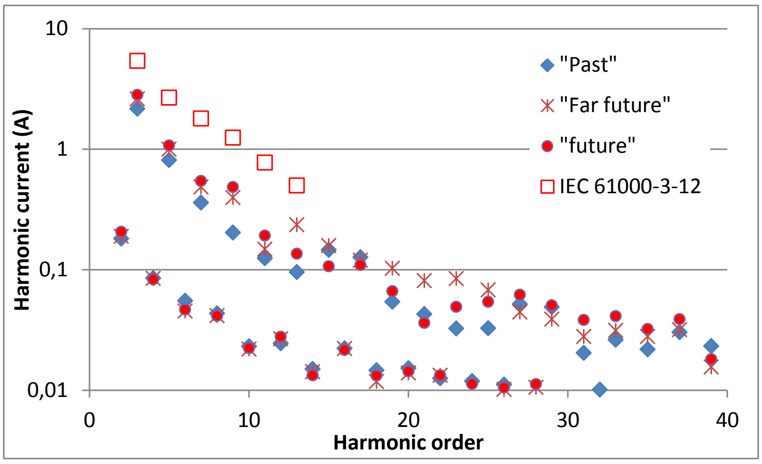


Fig. 6. 99% harmonic spectra for the domestic customer: three scenarios and IEC 61000-3-12 limits.Note the logarithmic vertical scale.

The squares in the figure are the limits that would be placed on the domestic customer in case it would be treated as a device, with a rated current of 25 A, under IEC 61000-3-12. The most strict limits, for a short-circuit ratio of 33, have been used. The harmonic emission increases for some of the frequencies due to the replacement, but for all relevant frequencies is the emission even in the "far future" scenario more than a factor of two below the limits according to IEC 61000-3-12.

The harmonic emission of this hotel is compared with the emission limits for equipment with rated power between 16 and 75 A, according to IEC 61000-3-12, in Fig. 7. The table for unbalanced equipment has been used, for a short-circuit ratio of 33. This results in the strictest limits. A rated power equal to 150 A has been assumed. Although the size of this load is strictly speaking outside the range for this standard, the relative limits have still been applied so as to get an impression of the severity of the emission.

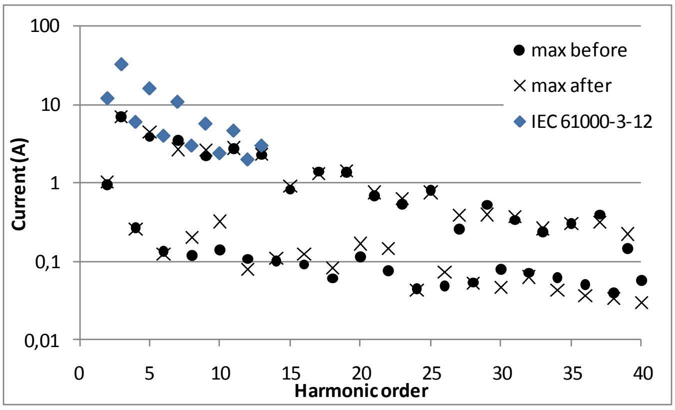


Fig. 7. Maximum of the 99% harmonic current spectra in the three phases for the hotel, before and after the replacement; comparison with the IEC 61000-3-12 limits; note the logarithmic vertical scale

The comparison shows that the current emission is below the limit for all harmonics covered by the standard. Harmonic 13 is closest to the limit, but the value of this one is not impacted by the replacement.

Fault-Level Requirements

The 99-% harmonic currents from the "past" and "far future" scenarios of the domestic customer have been used to estimate the fault-level requirements placed on the distribution network operator by this customer. It has been assumed that the source impedance increases linearly with frequency. The 95% voltage-distortion limits for customers connected to a public low-voltage network, according to EN 50160, have been used. Knowing the current emission I_h and the maximum-permissible voltage distortion $u_{h,max}$, the minimum-required fault level can be calculated, using Ohm's law. As shown in [5] the minimum required short-circuit ratio (ratio between the fault current and the rated current I_{nom}) is obtained from:

$$k_{min} = \frac{h \times I_h}{u_{h,max} \times I_{nom}}$$

Where h is the harmonic order. The minimum-required short-circuit ratio, for a rated current of 25 A is shown in Fig. 8 for the "past" and "far future" scenarios.

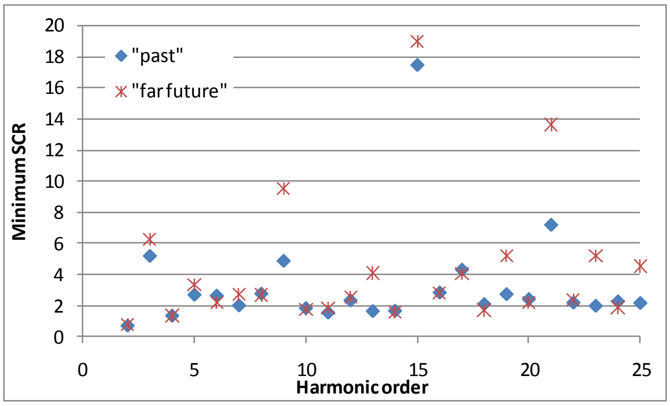


Fig. 8. Minimum-required short-circuit ratio for the domestic customer to keep the voltage distortion below the EN 50160 limits.

The higher the minimum-required short-circuit ratio, the higher the risk that the voltage-distortion limits will be exceeded. The values set by the harmonic emission, and shown in Fig. 8 should be compared with other requirements set on the short-circuit level. A study done by a network operator [7] resulted in a minimum short-circuit ratio of about 30 to prevent excessive steps in voltage due to load switching. The highest values from our measurement are obtained for the triplen harmonics 3, 9, 15 and 21. The voltage-characteristics and compatibility levels have traditionally been rather low for these harmonics. It should further be noted that the model used for the source impedance, linear increase with frequency, probably gives an overestimation of the required fault level for higher-order harmonics.

Reactive Power, THD, and Power Factor

The reactive power at the power-system frequency ("fundamental reactive power") is plotted versus the active power for the domestic customer in Fig. 9 and for the hotel in Fig. 10. The domestic customer is shown to generate reactive power during most of the measurement period; the hotel always consumes reactive power. For the domestic customer the figure shows a small increase in reactive-power production; the reactive power for the hotel is not impacted by the replacement.

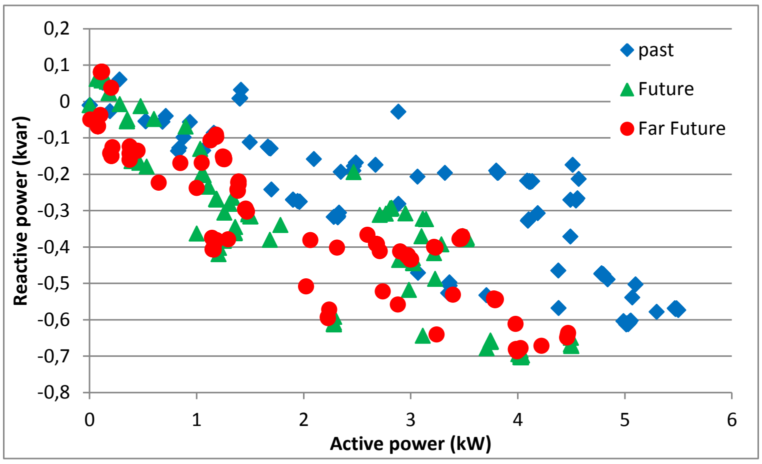


Fig. 9. Active power and (fundamental) reactive power for the domestic customer

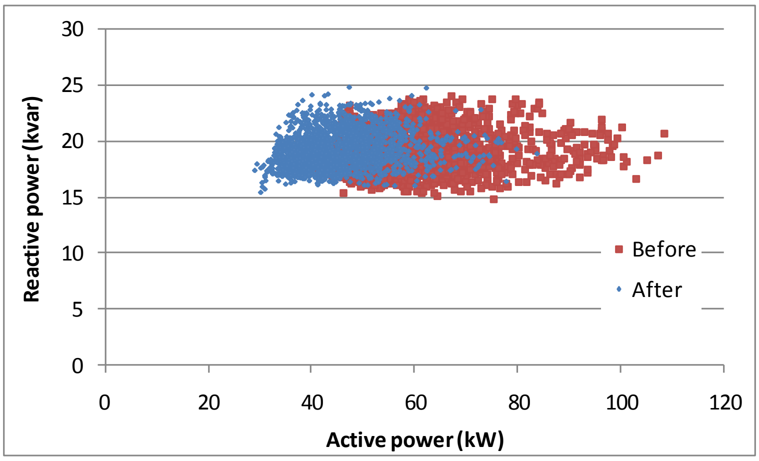


Fig. 10. Active power and (fundamental) reactive power for the hotel

For both customers the reactive power remains about the same whereas the active power becomes less. This will result in a smaller value for the displacement power factor (cos ϕ) of the total load. In the period before the replacement, 90% of the values for the hotel are between 0.86 and 0.99 (5% below and 5% above this range). The corresponding interval for the period after the replacement is between 0.82 and 0.97. The impact of the load on the power system does however not increase; it will sooner decrease because of the reduction in apparent power. The use of the displacement power factor to quantify the impact of a load on the system would result in the wrong conclusion in this case.

The total power factor (often referred to simply as “power factor”) is smaller than the displacement power factor; the difference is due to the waveform distortion. The total power factor is often used as an indicator for the impact of a specific device or installation on the power system. This may however again result in the wrong conclusions. The total power factor for the domestic customer is shown in Fig. 11. The values are lower for the Future and Far Future scenarios. These low values are however obtained only when the rms current is low. The total impact on the power system is lower during these periods than during periods of high power factor.

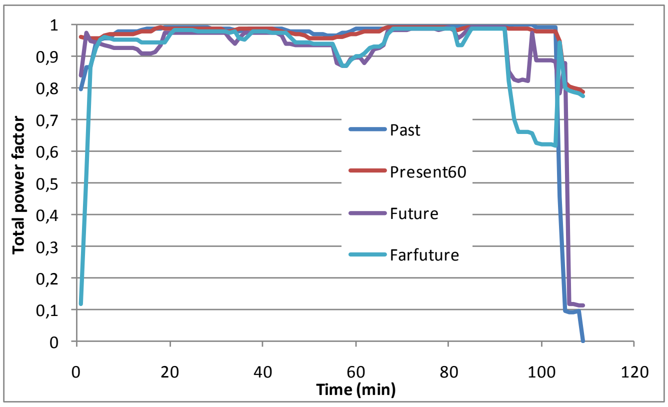


Fig. 11. Total Power Factor versus time for the domestic customer

Very low values of the power factor occur during the beginning and the end of the measurement period. This is when no equipment at all is in operation and the only active-power consumption is formed by the stand-by losses of the equipment. The stand-by current is mainly capacitive, hence the low power factor. A power factor slightly above 0.6 is obtained towards the end of the "far future" scenario; this is when the load only consists of identical LED. In the future scenario, the load consists during this part of the pattern, of a mixture of LED and CFL. Even though both have a power factor of 0.6, the power factor of the combination is over 0.8.

The power factor for the hotel, presented in Fig. 12, shows a decreasing trend throughout the measurement period. This is however almost exclusively due to the reduction in displacement power factor, which in turn is due to the reduction in active power. The total power factor is, throughout the measurement period, 99% or more of the displacement power factor. The waveform distortion thus causes 1% or less of the non-unity power factor, despite all unity-power factor lamps having been replaced by lamps with 0.6 power factor.

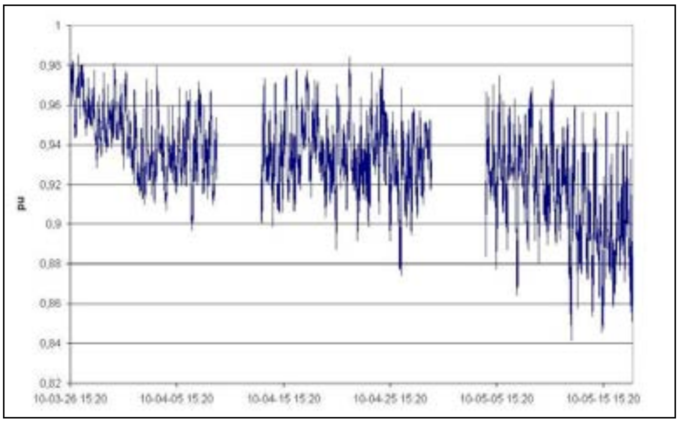


Fig. 12. Total power factor for the hotel during the whole measurement period.

The total harmonic distortion of the current versus time is shown in Fig. 13 for the four scenarios with the domestic customer. The waveform distortion, in terms of THD, shows a significant increase especially for "future" and "far future"; with distortion over 50% during part of the measurement period.

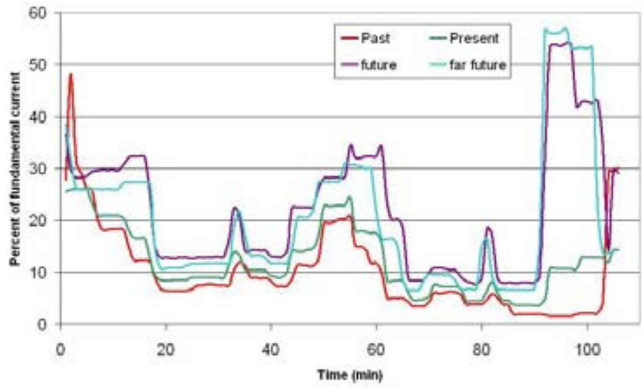


Fig. 13. THD of the current (in percent) versus time for the five different scenarios.

The total harmonic distortion is however only a measure of the non-sinusoidal character of the waveform; it is not a good measure for the grid impact of a load. Comparing Fig. 13 with Fig. 1 shows that high values of the THD occur during periods of low consumption. The impact of heavily-distorted waveform of low amplitude is less than the impact of a less-distorted waveform of high amplitude. What matters for the power system is not the THD in percent but the THD expressed in Ampere. The latter is the root sum square over all harmonic components, which can also be calculated as the product of the THD in percent and the fundamental current in Ampere. The THD in Ampere is shown for the domestic customer in Fig. 14. The highest values for the harmonic emission of the installation occur during the first half of the measurement period, when the heat pump is operating.

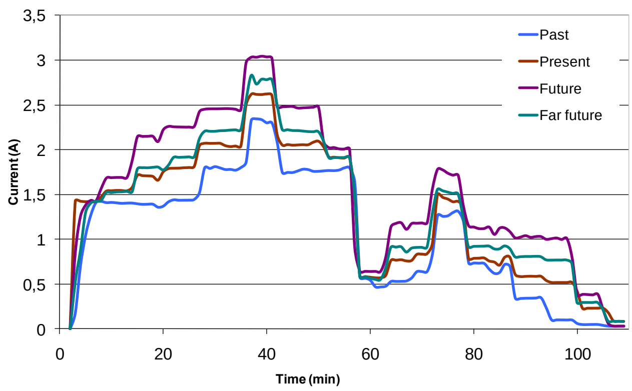


Fig. 14. THD of the current (in Ampere) versus time for the five different scenarios.

Comparing the “relative THD” in Fig. 13 with the “absolute THD” in Fig. 14, shows that the former has no relation with the actual impact of the installation on the grid. The relative THD should thus not be used to quantify the impact of an installation on the grid.

In order to get a fair value of the impact of the lights on the total harmonic distortion for the hotel, two 24-hour periods were selected where the number of rooms occupied was similar. One period with only a few rooms occupied was selected; and one where a large number of the rooms available was occupied. The results are shown in Fig. 15. After the lamps were changed the number of guests in the hotel did not have a strong impact on the current THD; the value is the same in phase three and the increase in phase one and two are 1% and 5% respectively. Before the replacement, the THD value increases in all phases when the number of rooms occupied goes from 15 to 59.

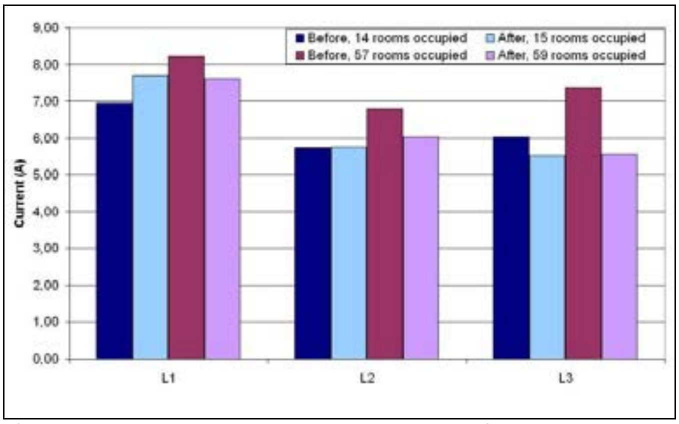


Fig. 15. The 95% value of the current THD, in Ampere with the hotel, for two 24 hour periods; L1, L2 and L3 refer to the three phases

Conclusions

Measurements with a domestic customer emulated in the laboratory and with field measurements of a hotel show that the replacement of incandescent lamps by LED lamps and CFL's gives a reduction in active power consumption (thus a reduction in local energy use), a reduction in peak current (i.e. a reduction in the loading of the grid), and a reduction in distribution-system losses (which gives a further reduction in energy use). All have a positive impact on energy efficiency and on the power-system.

The measurements for the domestic customer also show that the replacement results in an increase of the amount of so-called reactive power produced by the load. This has in most cases an overall positive impact on the grid, but the impact is too small for it to be any real value. For the hotel, no change in reactive power flow was observed.

For the domestic customer the replacement of incandescent lamps by LED and CFL results in an increase of the current distortion. The increase is however less than expected and the distortion from the experimental installation, despite its high amount of lighting, is still more than a factor of two below the limits set in an international standard (IEC 61000-3-12). The presence of other equipment, like a heat pump or a dish washer, impacts the current distortion much more than the replacement of the lamps.

The changes in current distortion for the hotel, before and after the replacement, are small, show increases as well as decreases and no impact is visible of the replacement of incandescent lamps by energy savings lamps. It is important to note that in both experiments so-called "low-power-factor lamps" were used. These are the ones that have the highest impact on the current distortion.

The laboratory experiment in which a full-scale electrical model of the domestic installation is reproduced in the laboratory has shown to be a suitable way of studying the impact of new equipment on the current distortion. It offers a compromise between the flexibility and reproducibility of a simulation and the accuracy of a field test.

With the field experiment at the hotel, other changes in consumption take place next to the replacement of the lamps: seasonal variations in temperature and amount of day light; as well as a variation in the number of rooms occupied. It has not been possible to completely remove the influence of this, so that the actual impact of the replacement could not be quantified. An important conclusion from this study is however that the impact is in any case small and smaller than the impact of other variations in consumption.

A comparison is also made of the additional requirements placed on the system strength by the replacement. These additional requirements are small and do not result in the need for any additional network-planning effort at this stage.

The study also confirms that the power factor is not an appropriate indicator to compare different loads. To compare the impact of different loads on the power system, a set of parameters should be used. The combination of active power, reactive power (in var); harmonic currents (in Ampere) and rms current (in Ampere) is a much better alternative.

Acknowledgements

Financial support from Philips, Skellefteå Kraft and the Swedish Energy Agency is gratefully acknowledged

References

[1] J. Arrillaga and N.R. Watson, Power System Harmonics, second edition. Chichester, England: Wiley, 2003.

[2] R.R. Verderber, O.C. Morse, and W.R. Alling, Harmonics from compact fluorescent lamps, IEEE Transactions on Industry Applications, Vol.29, No.3 (1993), pp.670-674.

[3] J. Cunill-Sola, and M. Salichs, Study and Characterization of Waveforms From Low-Watt Compact Fluorescent Lamps With Electronic Ballasts, IEEE Transactions on Power Delivery, Vol.22, no.4 (2007), pp.2305-2311.

[4] N.R. Watson, T.L. Scott and S. Hirsch, Implications for distribution networks of high penetration of compact fluorescent lamps, IEEE Transactions on Power Delivery, Vol.24, no.3 (2009), pp.1521-1528.

[5] S. K. Rönnberg, M Wahlberg, M. H. J Bollen, A Larsson, M Lundmark Measurements of interactions between equipment in the frequency range 9 to 95 kHz: CIRED 20th International Conference on Electricity Distribution, Prague 2009 paper id 0231.

[6] M.H.J. Bollen, L.Z. Yao, S.K. Rönnberg, M. Wahlberg, Harmonic and Interharmonic Distortion due to a windpark, IEEE PES General Meeting, July 2010.

[7] P. Norberg, A. Larsson, M. Sundell, U. Grape, Introducing network strength to handle power quality in system planning, CIGRE Sessions 2008.

A Survey of LED Standards and Markets in Asia

My K. Ton

ECO-Asia Clean Development and Climate Program

Abstract

It is widely accepted that light emitting diodes, or LEDs-based products, have the potential to contribute significantly in world-wide efforts to improving the energy efficiency of domestic and commercial lighting. In the last two years, LED-based lighting products have emerged as a credible, energy-efficient, long-lasting, and low-maintenance alternative for some real-world commercial and industrial applications. The development of LED-based lighting products for commercial and residential applications has also followed quickly, with thousands of products now available on the consumer markets in Asia. LEDs have also generated more interest, and new manufacturers seem to be entering the market daily.

The increasing demand for this once unfamiliar product has resulted in some significant changes in how LEDs are made and sold in Asia. These changes include:

- Accelerated LEDs demand and production;
- Increased product availability and variety;
- Concentration of LEDs manufacturing in regions with low labor and material costs;
- Initiation of a number of national efforts to develop standards for LED-based products; and
- Emergence of specific programmatic requirements for LED-based products.

The market trends for LED-based lighting products, especially for consumer lighting in Asia is beginning to resemble the path taken by CFLs, with fractured standards development efforts, multiple, conflicting performance requirements, and the same potential towards a “race to the bottom” in terms of product quality and consumer dissatisfaction.

The intent of this paper is to provide an overview of the market for LED-based lighting technologies, the issues and barriers to adoption, and development of standards for LED lighting in Asia in order to identify opportunities for harmonization of standards and regional program decisions regarding this new technology. It provides some background information on the current state of LED technology, standards activities, and efforts to promote LEDs products and around the region.

1 Introduction

In the last ten years, LED-based lighting products have emerged as a credible, energy-efficient, and long-lasting alternative for some real-world commercial and industrial applications. The development of LED-based lighting products for residential applications has also followed quickly, with thousands of products now available on the consumer markets in Asia. A number of projections have estimated that LED lighting will gradually replace at least 20% to 35% of incandescent lighting applications by 2020, if not earlier, due to a combination of increased consumer appetite, and regional and national programs.

The challenges (and the potential) for the adoption of LEDs in Asia are quite significant, and require thoughtful actions on the part of policymakers. For example, the market trends for LED-based lighting products, especially for consumer lighting in Asia have the potential to follow the path taken by CFLs not so long ago, with the same tendency towards a “race to the bottom” in terms of product quality, consumer dissatisfaction, and lack of a regionally agreed upon quality standard [1].

The intent of this report is to provide an overview of LED-based lighting technologies in Asia [2]. It examines the current market, technological issues and barriers to adoption of this technology in order to help policymakers identify opportunities, form program policies, and decisions regarding this new technology. The report provides some background information on the current state of LED technology and market, as well as standards activities and needs around the region. It is intended not to be a primer, but a guide of sorts for those who need to promote, test, and regulate LED-based lighting products.

2 The Asian Market for LEDs

Globally, the high-brightness LED market grew 11% in 2008, reaching $5.1 billion. This world-wide LED-based lighting market is projected to continue to grow. In fact, lighting and liquid crystal display (LCD) backlighting are the applications that are seen to be driving the market for high-brightness LEDs (or HB LEDs, which are needed for lighting applications) beyond 2010. Over the next five years, the market growth forecast for HB LED is at least at a CAGR (compound annual growth rate) of 24%, and is expected to reach $14.9 billion world wide in 2013. In Asia, the market for LEDs is rapidly expanding. Based on 2008 information, the current market size in Asia for LEDs can be assumed to be about US $7 to $8 billion in 2010, of which lighting constitutes about US $500 to $600 million and growing [3].

Japan, Singapore, Taiwan and Malaysia have long been major centers of LEDs and LED component manufacturing with respect to HB LED production. The most dramatic increase in LED production in the past decade happened in Taiwan and China. By most estimates, Chinese production of LED-based products currently accounts for a majority of products worldwide, both in lighting and other product categories.

According to experts, most illumination-grade chips being used in Chinese products are still imported from outside of China currently, from Tier II manufacturers in Korea (LG, Samsung) and Japan (Stanley and others), and from Tier I manufacturers (Cree, Nichia, Osram, Philips, Toyoda Gosei, and Seoul Semiconductor). There are probably several hundred LED packaging firms in China; the highest volume packagers are in Shenzhen and the Shanghai area. In addition to the chip and packaging companies, there are also several thousand LED application companies in China. The exact number is hard to determine, and in fact it is growing almost on an exponential basis.

China has eight other cities focused on LED production, each with its own specialty. Other than Japan, Singapore, Malaysia, and Taiwan, each with significant investments from the start, few other Asian countries have exhibited such significant growth in LEDs production capabilities. India, which is working to leveraging its developed expertise in IT industries to foster LED production, is just now at the beginning of this process.

It is important to note that similar to the personal computer industry, much of the profit in the LED industry is in chip production, with much lower margins in the packaging and application stages. Generally, LED chip production generally accounts for 70% of profits, and LED chip packaging accounts for about 30%. Up to several years ago, the production of HB LEDs was limited to a handful of companies in the US, Japan, Korea, and Europe that hold most of the intellectual properties on LED production processes. This trend is now changing, due to a number of factors, including constraint on production capacity, and the increased interests from both the Chinese and Indian governments in developing their own LEDs chip fabrication capacity and knowledge.

Most of China's current LED industry is in the chip-packaging segment and application development, which are less profitable. However, the Chinese government has been supportive of the industry in helping to expand LED chip manufacturing by offering subsidies designed to bring investment from Taiwan and elsewhere. The Chinese government is willing to subsidize 8-10 million RMB (US$1.2 - 1.5 million for each chip fabrication machine installation, and this level of incentive has attracted many LED chip makers from Taiwan to set up facilities in China.

3 General LED Performance and Cost Trends

The advances in compound semiconductors used for LEDs follow a trend predicted by Haitz's Law. It states that the light output and efficacy of LEDs roughly doubles every 18 to 24 months, and that the future LED performance will likely follow a trend similar to that of the past 30 years. Therefore, not only is the performance of LEDs improving, but the cost is also decreasing, making the technology more cost effective for certain applications. In the market place, the efficacy and cost projections of white LEDs, and are slowly being realized.

It is important to note that many comparisons of this type tend to be a simplification. The analysis does not include installation costs of lighting systems, nor are maintenance costs of the incandescent and LEDs systems taken into account. There are also simplifications that make some LED predictions not so favorable. The efficacy of a LED is dependent on the whole system, consisting of the LED chip, the packaging – including the design of the LED package and the heat sink, its power supply and "driver." These components have their own efficiency values and power requirements that are not yet standard in the industry and therefore cannot be predicted.

4 Measuring and Reporting LEDs Performance

LEDs represent a lighting technology fundamentally different than that of the incandescent, fluorescent, or other gas-discharge light sources. Measuring LEDs and reporting LED output for use in place of traditional lighting sources actually represent a significant challenge. A similar challenge to LED measurement and reporting exist in the classification and application of LED-based lighting products. There are two fundamentally different applications for lighting: luminance – where we look directly at the light source, and illuminance – where light sources are used for illumination. Each application has a corresponding set of measurement methods, standards, and tools that may not be applicable, or require significant adaptation for LEDs-based lighting, such as:

- Measuring directionality
- Comparison method for light sources
- Measuring color characteristics
- Measuring efficiency
- Measuring reliability and lifetime

In addition to the above standard needs, LEDs lighting devices also require new controls and safety standards.

5 Near-Term Opportunities for LED-based Lighting for Asia

It will be only a matter of time before LED-based lighting will be one of the mainstays in the residential, commercial, and industrial markets. In the near term (one to three years), LED-based lighting products will first see specific application in the commercial and industrial arenas. Even with the recent pace of product development, Asia's residential market will not see large adoption of LED products within this near-term timeframe.

For Asia, LED-based lighting products will likely to make a significant impact in the near-term include the following areas: outdoors and roadway lighting, transportation-related functions, and architectural applications, based on current costs and energy savings potentials. ECO-Asia's review of the available data on actual, documented cases regarding installation of LEDs in comparable applications that can be verified with performance test data, shows that:

- LEDs are generally yet not cost-effective in indoor, general/ambient applications, especially in retrofit cases.

- LEDs are most cost-effective in situations where they are displacing a traditional light source in an application with high duty-cycle.

- Available performance and cost data show that LEDs are not yet ready to displace the best fluorescent applications – the linear fluorescent T8 or T5 lamps [4].

- Available "best in class" LEDs are now comparable to incandescent and halogen in some applications, but have yet to surpass CFLs in cost-effectiveness for general lighting situations, especially in most residential applications [5].

LEDs will continue to make additional impacts in areas such as traffic signals, exit signs and signage. However, it is important to note that LED products have the potential to be “disruptive” and may find other niches that are not in these broadly outlined categories.

6 LED Standards Development Options for Asia

The fact that LEDs are a fundamentally different new light source poses a challenge to those who must set standards and policies for this new technology. The ECO-Asia team conducted a survey on technical standards, national regulations, testing and labeling requirements, and other performance and quality requirements that address LEDs available for sale in Asia. The results are summarized below in Table 1. Additional details regarding specific standards and categories are included in Appendix A.

Table 1. Overview of LEDs Standards Activities in Asia

Country/Region	LEDs Standard Activities?	Specific Application Category Under Development	Responsible/Lead Organization
Brunei	None	None	Energy Division of PM Office
China	Task Teams formed	Street, devices, lamps	CNIS, others
Hong Kong	Task Team formed	None	EMSD
India	Task Team formed	Street lighting, off grid	BIS
Indonesia	Testing standards being developed	LEDs for solar homes	DGEEU, NSI
Japan	A number of standards have been published	See Appendix B	JELMA, JIS
Malaysia	Under consideration	Not yet decided	Standards Malaysia
NZ	Yes, Task Team formed	Street lighting	EECA
Philippines	2010 Designated for LED standards	Modules/General Safety	BPS
Taipei	A number of standards have been published.	See Appendix B	BSMI
Thailand	Under development	LED modules	TISI
Vietnam	No	NA	VSQI

7 Summary and Recommendations

It is important to note that LEDs will not displace all other light sources. Rather, it will be one of the mainstays of energy efficient lighting. The versatility of incandescent lighting for many tasks, as well as with over a century of investments and development of all things lighting centering around this light source, means that its legacy will not be easily or quickly changed. In addition, developments in the existing light sources have not stopped. Thus, the future of energy efficient lighting will require that each light source be used to their best advantage.

Nevertheless, in order for LEDs to achieve their potential for energy efficiency and widespread adoption, and used to their best advantage, it is clear that policies and standards need to be developed for LEDs. As discussed earlier, LEDs represent a fundamentally different, new light source, and the characteristics of LEDs may not be adequately described by current metrics, combine to pose a challenge to those who must set standards for this new technology. In addition, because it may not be possible to apply any of the current standards towards new LEDs, new standards have to be developed or updated for almost every application categories to insure that LEDs characteristics are taken into account.

Thus, for policymakers, standards-setting bodies and agencies across the region, an immediate standards and policy "triage" of sort is required for LEDs. Based on ECO-Asia's review of the majority of available data on actual, documented cases regarding installation of LEDs in comparable applications that can be verified, policymakers and standard setting agencies may wish to focus on the following application areas for LEDs initially:

- Area, parking, street and/or outdoor lighting: This is a high-interest, high duty application area, and policy support for standards may be easily obtained. However, standards for these application areas can be very involved, as related standards such as pole height, distribution, illumination levels, etc. may also need to be revisited, adding to the time required;

- Traffic lights and transportation-related signals: These are high-duty applications, and can yield significant savings both in energy and maintenance costs, even if they are not as visible as other applications. Changing transportation and traffic-related lighting may also require code or regulation changes in addition to changes in standards [6].

- Signage and architectural applications: Similar to traffic and transportation-related applications, these are high-duty cycle, and are also increasing in number as more commercial buildings are being built and retrofitted around the region.

- Off-grid lighting applications: This is an application that has gained significant interest in recent years, as a new generation of low-wattage LEDs are starting to meet some basic rural lighting needs. These have the potential to serve a large percentage of Asia not yet connected to the grid. Like street lighting, complementary standards will be needed, such as charging and battery capacity, for example [7].

LED products have the potential to be "disruptive" and may find other niches that are not in these above broadly outlined categories, and may or may not be limited to their traditional distribution channel for their product categories and applications. In addition, the lessons learned from the introduction of CFLs indicate that while consumer-orientated LED products (such as incandescent lamp replacement) are not yet cost effective, a number of steps, including quality standards, must be put in place soon for consumer products to protect early adopters from exaggerated claims and products with dubious performance and reduce the risks of these products "poisoning" the market.

Finally, there are a number of considerations that policymakers in Asia may wish to consider when considering the growth of LEDs:

- Roadmap for LED-related policies: Policymakers will require a roadmap for LED categories for standard setting, regulation and promotion based on industry development progress and potential impacts to guide their decisions. Policymakers may also want to consider a regional, on going effort to coordinate on a regional roadmap for LED categories based on the potential impacts in terms of energy savings and costs. This will allow a continued "triage" for standards and regulation development that can allow policymakers and standard setting agencies to keep pace with the industry.

- A regional effort on LED standards and labeling: A regional effort towards harmonization of standards and labeling for LEDs can help to speed up adoption of quality LED-based products and reduce the overall efforts needed around the region. Currently, there is no recognized set of common quality criteria for LED-based products in place across Asian consumer or commercial markets. This presents an opportunity for harmonization of quality standards that can help to reduce confusion, speed up adoption, and to send the right economic message to suppliers and developers of quality LEDs in Asia.

- Quality is essential: A hard learned lesson from the introduction of CFLs into the Asian markets was low-quality products can undermine energy-efficiency policies and efforts to mitigate greenhouse gas emissions. High-level policymakers need to recognize that the prevalence of low-quality LED products in the market will again constitute a significant barrier to the full realization of energy-efficiency policies. Given that first costs for new LED-based products are much higher than CFLs (on a per-unit basis), it is imperative that public and private investments should be made as wisely as possible [8].

- Use available regional institutions: Currently, many countries focus their standards on energy efficiency and energy performance and do not explicitly incorporate other quality criteria into their standards. Therefore, an initial step for the regional harmonization process can begin by identifying some common performance characteristics for LEDs that can insure energy, light output and lifetime performance to provide a minimum level of product quality in the market. There are three regional initiatives that can serve as suitable vehicles for such a regional effort:

    - The Asia Lighting Compact – ALC, based in Singapore, is a regional, independent, public private partnership whose mission is to promote standards harmonization, product quality, and adoption of energy efficient lighting. It has worked with regional stakeholders to develop a set of quality standards for CFLs in Asia.

    - The Regional Center for Lighting – RCL, based in Sri Lanka, is a technology hub for lighting in Asia. RCL's mission is to advance sustainable lighting and make it affordable to improve the well-being of the citizens and the countries within the region. It is developing a technology and knowledge portfolio and laboratory capacity.

    - lites.asia – lites.asia stands for Lighting Information and Technical Exchange for Standards. The objective of lites.asia is to facilitate a greater involvement by Asian / APEC countries in the development of IEC standards. This should result in standards which are more appropriate for regional needs, thus enabling Asian / APEC countries to adopt IEC specifications with minimum local variations.

- A combined, coordinated effort by these organizations can help advance both the technology roadmap and standards harmonization for the region. They can also work together to arrive at the recommended performance and quality categories, as well as recommended product categories, test methodologies, data sharing plans, etc. suitable and acceptable for all agencies and stakeholders in Asia.

- Develop guidelines for municipalities: Currently, many municipalities and agencies are in the throes of "LEDs-fever." They are determined to make investments in LEDs at all cost, or are confused by misleading performance and lifetime claims when carrying out cost-benefit analyses. One possible approach to address this issue is to develop an one-page guide for evaluating LEDs and product claims that officials and agencies can use to screen out dubious products. A follow up step would be to seek support for a regional municipal public lighting organization, whose purpose is to disseminate information regarding best practices in public and municipal lighting for agencies in the region.

- Develop guidelines (and labels) for consumers: Similar to the many municipalities and agencies, consumers are also blinded by exaggerated and unverified claims of performance and quality. As a result, low cost consumer products are appearing in many markets without any oversight or recourse for consumers. This remains a preventable disaster. Energy or consumer agencies can work with a recognized regional organization on product quality – such as the Asia Lighting Compact – to develop a consumer guide and/or a label to help consumers choose quality products. This guide can use common descriptors of performance and quality for consumers around Asia, and can help prepare the market for quality products.

References

[1] *Confidence in Quality: Harmonization of CFLs to Help Asia Address Climate Change*. US Agency for International Development, Regional Development Mission, Bangkok, Thailand, 2007.

[2] While this report broadly applies to the Asia region, the information presented herein focus primarily on China, India, and four countries holding membership in the Association of Southeast Asian Nations (ASEAN) – Indonesia, Philippines, Thailand, and Vietnam. Together, these six nations account for 96 percent of the gross domestic product (GDP) of Asia's developing economies as well as a significant share of the global LED lighting market.

[3] Due to intense industry interest in LEDs, the exact size and production numbers can be difficult to come by or to verify. The information presented in this report is a compilation of publically available information, and is used to illustrate the overall size and growth of the industry in Asia.

[4] http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lightfair7_mccullough-caliper2.pdf

[5] The latest round of US DOE CALIPER testing of LEDs replacement for IR reflector halogen applications shows that LEDs do not deliver similar center beam candlepower (CBCP) yet.

[6] "Asia Pacific region to develop 350 new airports over a decade, with more than USD100 billion in investments." Frost & Sullivan, Jakarta, Indonesia, 12 Nov 2010.

[7] See, for example "'Lighting for All' Scheme to Bring Clean Energy to 50 Million Asians" Asian Development Bank (ADB) and The Energy and Resource Institute (TERI) press release, 29 October 2010, New Delhi, India. Also Lighting Africa at: www.lightingafrica.org.

[8] For example, see: http://blog.mlive.com/grpress/2008/08/led_lights_fail_to_illuminate.html; or, http://www.punchng.com/Articl.aspx?theartic=Art201011250185978

Testing efficient luminaires and LED retrofit lamps – experiences from Switzerland

Eva Geilinger, Stefan Gasser, Eric Bush, Toni Venzin

Topten International Services

Abstract

Luminaires play a role when it comes to generating energy-efficient light. Efficient light bulbs are promoted for homes today, but consumers don't get any information about domestic luminaires and how efficient they are. To close this gap, a test method for domestic luminaires was developed in Switzerland. Experiences from the past three years show that retailers and manufacturers are considerably interested in such information. The main benefits are firstly to gain information for buyers and customer service, secondly to get product data from independent measurements.

With this article we intend to give clues and motivation to retailers on how to communicate efficiency and quality of domestic luminaires to their customers. The relevant parameters are named. Measurements of more than 150 products show in what range the good products are. Topten[1] evaluates the best products and presents them online. Energy savings can be determined compared to typical luminaires that have been measured as a reference. Examples are shown how retailers use the test results to promote these efficient luminaires to their customers.

One chapter is dedicated to a test of 14 LED retrofit lamps that was made in Switzerland in the end of 2010. Since the LED retrofit lamp market is expanding rapidly, it is important to know the quality of these new products. The test results show that many LED retrofit lamps are of high quality and efficiency, and also identifies the critical parameters.

Introduction: Swiss tests of domestic luminaires and LED retrofit lamps

Today, consumers don't get any information about the efficiency of a domestic luminaire they intend to buy. The focus is on the light bulbs, for many of which an energy label is mandatory (excluded are spot lamps). However, the luminous efficacy of the lamp does not tell how much light is actually coming out of the luminaire.

To close this gap, Topten[1] and the University of Applied Sciences HTW Chur developed a test method for domestic luminaires in Switzerland. The goal was to obtain the significant specifications for efficiency and quality with an easy, practical and therefore cost-effective procedure. The domestic luminaires are sent for testing by two large swiss retailers as well as other retailers and specialist shops. Since the opening of the laboratory in 2008, over 150 domestic luminaires have been tested.

With LED retrofit lamps, a new technology for replacing incandescent and halogen lamps is coming to the market. The product range is expanding rapidly and it is important to know the quality of these new products. An interesting product test was made by the Swiss Agency for Efficient Energy Use S.A.F.E. in the end of 2010 and we dedicate a chapter of this article to it.

---

[1] Topten is a consumer-oriented online search tool, which presents the best appliances in various categories of products. The key criteria are energy efficiency, impact on the environment, health and quality. As a communication tool it helps to show how our energy consumption causes climate change and what we can do personally to reduce our impact. It is also a powerful instrument to influence manufacturers. Topten was launched in 2000 in Switzerland. Since then, sixteen European national Topten sites have been established, as well as sites for USA and China. See www.topten.eu

Important parameters: knowing the efficiency and quality of luminaires

For judging how efficient a luminaire is, one must know how much electric energy is used and how much light is coming out of the luminaire. There are two approaches to determine how much light is given by a luminaire: Either measuring all the light coming out of the luminaire (luminous flux) or measuring how bright the user surface is being lit (intensity of illumination). These parameters must be determined:

- energy consumption during use and standby
- luminous flux (lumen) or intensity of illumination on the use surface (lux or lx)

For judging the quality of LED luminaires, the color rendering index CRI and color temperature (kelvin) are determined in the test method mentioned in this article.

Energy consumption

The data for energy consumption during use and standby can be used to estimate the annual energy consumption of the luminaire in kWh per year. We suggest that 760 hours use and 8000 hours standby are a reasonable and realistic usage pattern (according to Topten and the University of Applied Sciences HTW Chur).

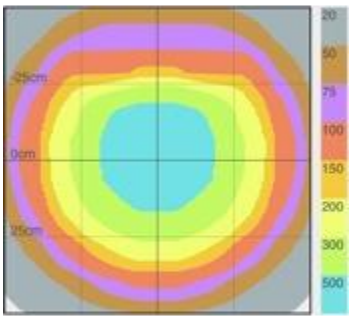
Example: energy consumption of a table luminaire (LED)

Energy consumption during use: 10W
Energy consumption during standby: 0.4W
Estimate for annual energy consumption:
(760h/year * 10W + 8000h/year* 0.4W) / 1000kW/W = 11 kWh/year

Luminous flux and intensity of illumination

The luminous flux in lumen describes the total amount of light which is emitted from a light source into the room. It is most commonly measured in a goniometer, a rather expensive apparatus. Topten and the University of Applied Sciences HTW Chur aimed for a more cost-effective procedure. A new light laboratory has been installed that allows determining how bright a surface is lit, therefore measuring the intensity of illumination on the user surface (in lux) instead of the luminous flux. First experiences with this method of luminaire testing could be gained in cooperation with several Swiss retailers.

In a standardized room (3 x 3 x 2.4 meters), a robot measures the intensity of illumination (lux) at 100 spots on the ground surface. This measurement gives a very good indication of the light that can be used on work tables or dining tables for examples. There are other types of luminaires which are meant to illuminate rather a room than a surface. To take into account the light that is emitted all around, the paint on walls and ceiling has defined degrees of reflection. The ground surface is illuminated indirectly by the light reflecting from walls and ceiling. For each type of luminaire the height of the light source as well as the size of the use surface was defined based on the typical usage.



Measurement area 1 m^2 Lux

Example: distribution and average intensity of illumination on measurement surface (same table luminaire as above)

Average intensity of illumination on measurement area: 174 lux

Maximum intensity of illumination: 775 lux

Area illuminated stronger than 500 Lux: 0.11 m^2

Energy efficiency

With the described measurements the energy efficiency is determined in kWh per year and per 100lx average intensity of illumination on measurement area. For the table luminaire in the examples above it is 6 kWh/year/100lx.

Color rendering index

The color rendering index (CRI) informs about the quality of the light compared to daylight. Especially for LED, where there are very big differences, it is important to inform the buyers about the color rendering index.

- Daylight: 100
- Incandescent and halogen lights: 100
- Energy saving lamps: 80
- LED: 50 to 95

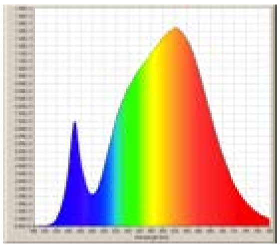
Color temperature

The color temperature indicates if the light is slightly blue or red. Slightly red light is called warm white, whereas slightly blue light is referred to as cold or daylight white. In between is the so-called neutral white. It is measured in kelvin.

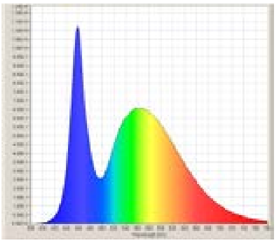
- Warm white: 2700 to 3500 kelvin (incandescent lamps 2700 kelvin, halogen 3000 kelvin)
- Neutral white: 3500 to 5000 kelvin
- Cold or daylight white: 5000 to 10000 kelvin (daylight 6500 kelvin)

All incandescent and halogen lights are warm white. Fluorescent lamps (FLs) and LED lights exist with a broad range of color temperatures. LEDs get more efficient with higher color temperature. Therefore LED luminaires often have cold white light. In Switzerland (and possibly other countries in Europe) people prefer warm white lights though. This has lead to disappointment with LED luminaires in the past. It is therefore important to inform buyers about the color temperature.

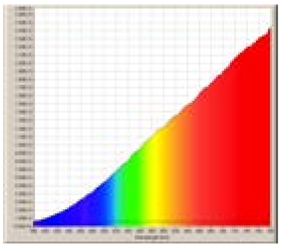
Examples of color spectres:



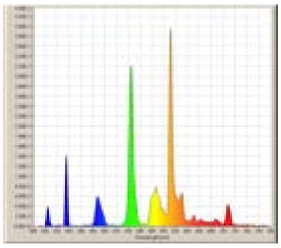
Warm white LED



Cold white LED



Halogen lamp

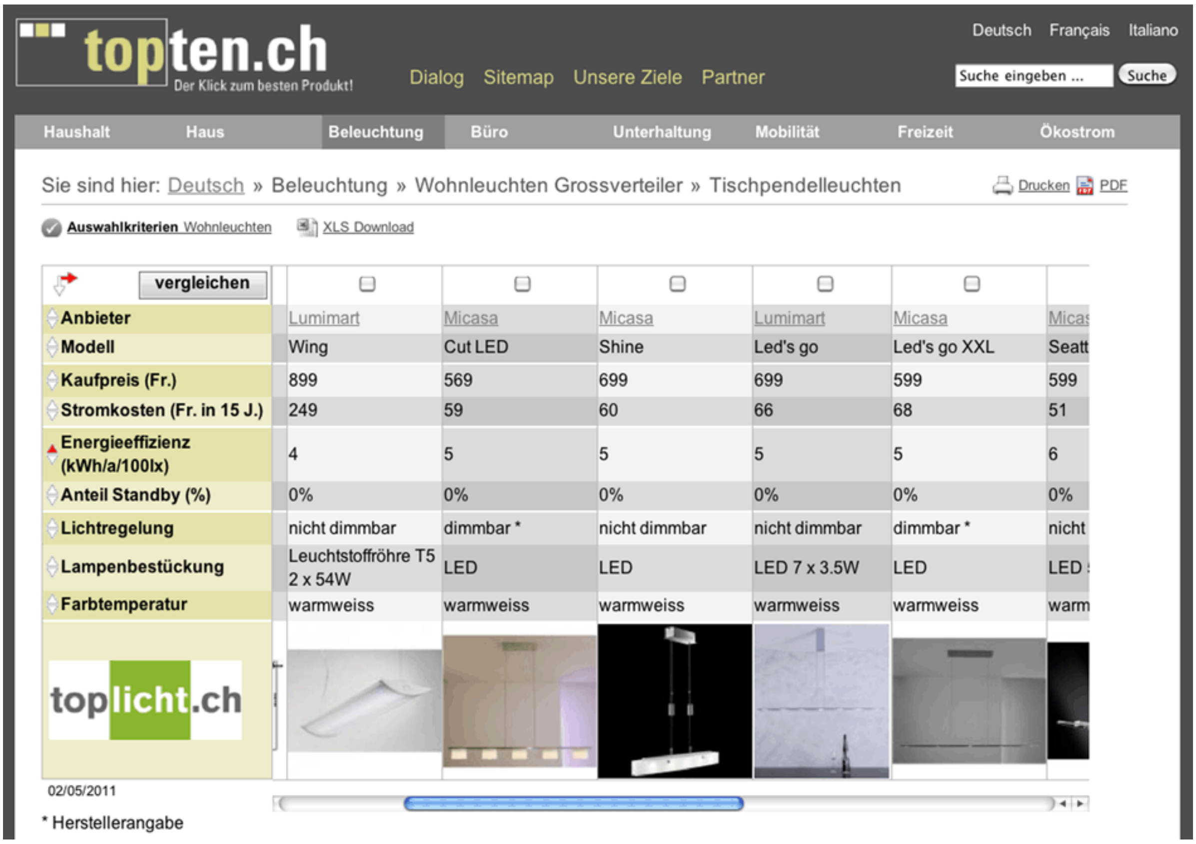


Energy saving lamp

Topten: Choice of the best luminaires

Several Swiss retailers send domestic luminaires for testing at the University of Applied Sciences HTW Chur. They receive for each luminaire a detailed protocol of the measurement. In addition, the luminaires are evaluated and the best ones are labeled by Topten Switzerland and presented online. Luminaires that fulfill the criteria defined by Topten Switzerland (see below) are published on the Internet (www.topten.ch). In order to create more publicity for these efficient luminaires, Topten Switzerland supports the retailers with the labeling and promotes articles in different media (customer magazines or trade journals).

Example: Screenshot of the best luminaires for dining tables on www.topten.ch (in German)
The table contains the following information: retailer, name of product, purchase price, electricity costs in 15 years, energy efficiency (kWh/year/100lx), part of energy used in standby, dimmability, lamp type, color temperature.



vergleichen						
Anbieter	Lumimart	Micasa	Micasa	Lumimart	Micasa	Micas
Modell	Wing	Cut LED	Shine	Led's go	Led's go XXL	Seatt
Kaufpreis (Fr.)	899	569	699	699	599	599
Stromkosten (Fr. in 15 J.)	249	59	60	66	68	51
Energieeffizienz (kWh/a/100lx)	4	5	5	5	5	6
Anteil Standby (%)	0%	0%	0%	0%	0%	0%
Lichtregelung	nicht dimmbar	dimmbar *	nicht dimmbar	nicht dimmbar	dimmbar *	nicht
Lampenbestückung	Leuchtstoffröhre T5 2 x 54W	LED	LED	LED 7 x 3.5W	LED	LED
Farbtemperatur	warmweiss	warmweiss	warmweiss	warmweiss	warmweiss	warm

Criteria: So what *is* a good luminaire (according to Topten Switzerland)?

After having measured over 100 luminaires, Topten Switzerland set the following benchmarks regarding efficiency:

- 8 kWh/year/100lx for spots and table luminaires (measured on an area of 1 m^2 at 0.5 m height)
- 8 kWh/year/100lx for luminaires for dining tables (measured on an area of 1 m^2 at 0.75 m height)
- 32 kWh/year/100lx for luminaires installed on the ceiling and freestanding lamps (area of 9 m^2)
- 50 kWh/year/100lx for luminaires installed on the wall at 1.7 m height (area of 9 m^2)

In addition, Topten Switzerland demands the following qualities:

- the supplier or manufacturer must have ISO certification (series 9000 and ideally 14000)
- conventional ballasts are not accepted, only electronic ballasts
- energy consumption during standby max. 1 watt
- color rendering index CRI min. 80
- LED luminaires must have a color temperature below 3500 kelvin
- luminaires for reading must get 500 lux on an area of an A4 paper sheet (0.07 m^2)
- luminaires for work tables must get 500 lux on an area of an A3 paper sheet (0.13 m^2)

Efficient luminaires and how much energy they save

Here examples are shown for the two most popular luminaire types. For more examples, see the website www.topten.ch (German, French, Italian).

Product comparison 1: Typical vs. efficient freestanding lamps. The energy saving in 15 years is about 2000 kWh.

			
	Typical freestanding lamp	Topten luminaire example 1	Topten luminaire example 2
Lamp type	Eco halogen R7s 230W	Fluorescent T5 2GX13 40W	Energy saving lamps E27 3x20W
Average intensity of illumination on 9m^2	132 lux	119 lux	166 lux
Energy consumption	225W	39W	51W
Consumption per year	171 kWh	30 kWh	39 kWh
Efficiency	130 kWh/year/100lux	25 kWh/year/100lux	23 kWh/year/100lux
Saving in 15 years	-	2115 kWh	1980 kWh

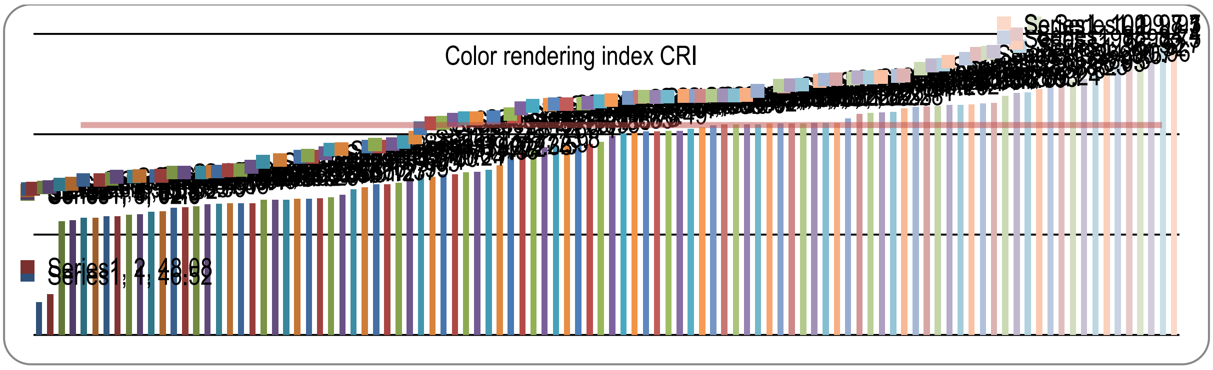
Product comparison 2: Typical vs. efficient spots. The energy saving in 15 years is about 420 kWh.

			
	Typical spot	Topten spot example 1	Topten spot example 2
Lamp type	Halogen 50W	LED 5W	LED 3W
Average intensity of illumination on 1m^2	105 lux	124 lux	46 lux
Energy consumption	44W	6.5W	4.4W
Consumption per year	33 kWh	5 kWh	3 kWh
Efficiency	32 kWh/year/100lux	4 kWh/year/100lux	7 kWh/year/100lux
Saving in 15 years	-	420 kWh	450 kWh

LED and color rendering index CRI

The color rendering index CRI varies greatly with LED luminaires and should be paid attention to. Experiences from Switzerland indicate that every second LED luminaire model may have an unsatisfying CRI below 80. See figure on next page.

Color rendering index CRI of 102 LED luminaires which were measured in the light laboratory. Only half of them (53) have a CRI above 80. Every third (30) has a CRI even below 70.



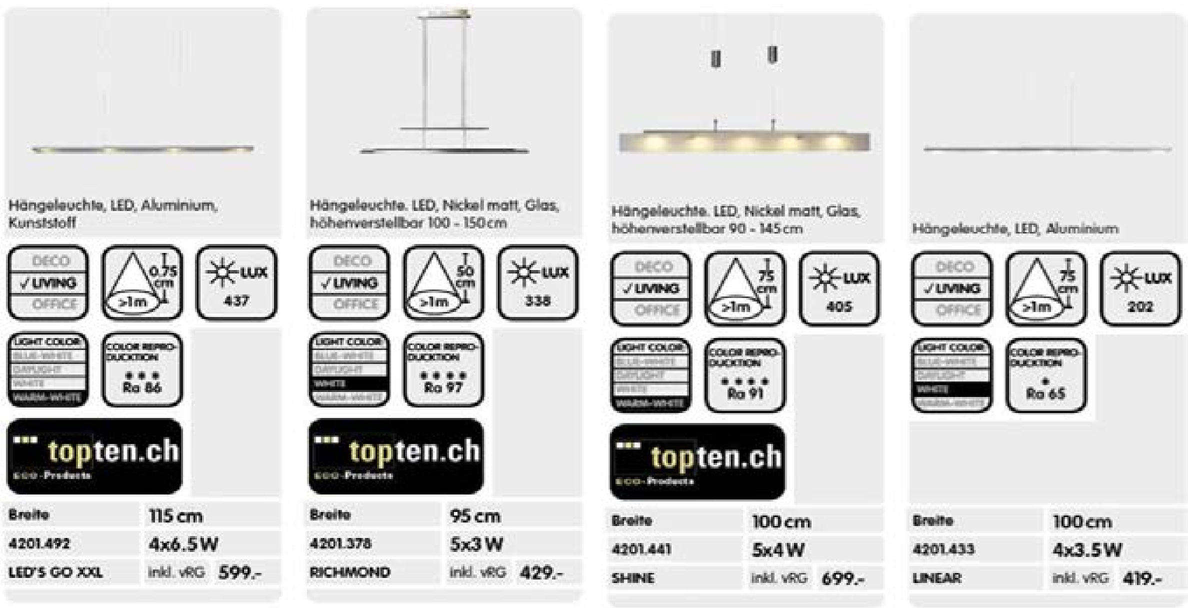
Partnerships with retailers

Several retailers in Switzerland use Topten as a label to promote these efficient luminaires to their customers (e.g. labeling at point of sale, print materials…). Procurement managers of the retailers ask increasingly for Topten requirements when selecting luminaires. They welcome guidance on specifications for efficiency and quality.

Example 1: The view of a retailer. The Category Field Manager Lighting of a retailer explains why they send luminaires for testing to the University of Applied Sciences HTW Chur.

One reason is customer service. The intensity of illumination on the use surface is important information for the customers as well as the luminous flux. It is used to classify the assortment of luminaires into decoration, use at home and use at the work place. Another reason is the independent measurement of photometrical and electrical parameters. Especially with LED, product data is sometimes imprecise.

This specific retailer uses the test results in Flyers for customers and sales staff as a support for selling (see picture below). The test reports are all available on the Intranet for the sales staff as well. It is planned to declare the average intensity of illumination on the product label. If a product fulfills the Topten criteria, this will also be indicated on the product label. These actions are communicated in customer magazines and other media. The retailer can demonstrate that they value efficient use of energy and take the role as a trailblazer.



Example 2: How Topten is used as a label in the shop and in the catalogue

Domestic luminaires: Types and market

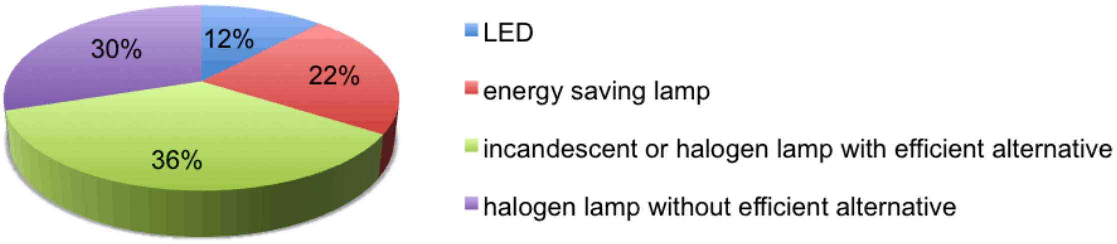
				
Freestanding lamp	Spots	Suspension	Ceiling/Wall	Table
Common lamp types:				
bulb (E27), halogen stick (R7s)	halogen spot (GU10, GX3.5)	bulb (E27), halogen pin (G9)	bulb (E27), FL tube T5 (G5)	bulb (E27)

The most common sold luminaire type is the freestanding lamp, followed by spots, then luminaires for suspension, ceiling/wall and table. Next to these examples, there are many different designs and many purposes (decoration, furniture in-built, garden / outside).

Typically, a model may stay on the market for 3-5 years, a fashion model 1-2 years. Only few classics are sold over many years. In recent years, more and more LED products are appearing in the assortments. The figure below shows that LED luminaires can make over 10% of the products range. In Switzerland, LED products are possibly advancing faster into the market than in other countries.

2 million domestic luminaires are sold annually in Switzerland. The total market without light sources is 100 million Euros [1]. The professional market in comparison amounts to 300 million Euros per year, by guess this is 2 million sold units as well.

Domestic luminaires of a big Swiss retailer by light sources (assortment 2010) [1]



If one is dissatisfied with the color temperature or amount of light emitted from a luminaire, it can partially be adjusted by exchanging the light bulbs. This works for luminaires with CFLs, halogen or incandescent lamps. FLs mostly cannot be replaced with a higher or lower wattage. LED luminaires generally contain integrated, non-exchangeable light sources. However, there's a rapidly growing choice of LED retrofit lamps that fit into the most common sockets like E27, E14, GU10, GX3.5.

New technology: LED retrofit lamps in the test

Since the LED retrofit lamp market is expanding rapidly, it is important to know the quality of these new products. For this purpose, S.A.F.E. tested 14 LED retrofit lamps in the end of 2010 (link to Swiss television show about this test see [2]; an english summary of the test results is available for PDF download on www.topten.eu). The main results of this test are:

1. High Efficiency: Most tested lamps are as efficient or better than compact fluorescent lamps (about 60 lm/W). The best LED retrofit lamp in the test had 94 lm/w, the weakest 34 lm/W.

2. There are many LED retrofit lamps that can replace an incandescent lamp with 20 - 30 watts, comparing the light flux (lumen). In the test were also three lamps that can even replace an incandescent lamp with 60 watts.

3. Some manufacturers give imprecise product information. Notedly when it comes to the replacement of incandescent lamps, as sometimes LED products with 20 – 50% lower light flux are recommended as replacement.

4. Good light quality: All tested lamps have warm white light (2600 – 3500 kelvin) and usually a good color rendering index (over 80, max. 92). However the CRI needs attention: four tested lamps had a color rendering index of only 55 – 68.

5. Only one of the tested LED retrofit lamps matched an incandescent lamp (blue line) in its light distribution (Philips 12W). All other products resemble rather a spot's light distribution with little light to the back and side.

Philips 12W	Osram 12W	Ledon 10W	Evenlight 5.5W	Paulmann 7W

Examples: The 3 best and the 2 worst LED retrofit lamps in the test

		Philips 12W	Osram 12W	Ledon 10W	Evenlight 5.5W	Paulmann 7W	*Incandescent 60W*
							
Consumption	W	12.8	13.5	9.4	5.7	5.7	*60.0*
Light flux	lm	823	909	589	331	194	*700*
Efficiency	lm/W	64	68	63	58	34	*12*
Replacement (real)	W	61	66	47	31	20	*60*
Replacement (Info)	W	50	60	60	50	-	-
Color temperature	K	2670	2722	2710	3415	2516	*2700*
CRI	-	81	86	92	66	78	*100*
Dimmable		Yes	No	Yes	No	Yes	*Yes*
Proportion of light back/side/front		14/61/25	0/38/62	2/16/82	0/27/73	0/34/66	*16/52/32*

Standards and regulations relevant for domestic luminaires

Standards

EN 13032-1: Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 1: Measurement and file format.

EN 12464-1: Light and lighting - Lighting of work places - Part 1: Indoor work places. (This standard contains criteria for limiting glare).

Annex III of Commission Regulation (EC) No 244/2009 of 18 March 2009 names further standards for the testing of lamps.

Requirements

Commission Regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps.

Commission Regulation (EC) No 859/2009 of 18 September 2009 amending Regulation (EC) No 244/2009 as regards the ecodesign requirements on ultraviolet radiation of non-directional household lamps.

Commission Regulation (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.

- Excluded from these European requirements are directional lamps.
- There are no efficiency requirements for luminaires.
- In 2011, the European Commission possibly presents first drafts for a directive with implementing measures for directional lighting: a first working document on halogens and LEDs is awaited. A legislation on luminaires or 'lighting design' could also be proposed.

Labeling

Commission Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps.

- Excluded from this European directive are lamps with an input power of less than 4 watts and reflector lamps.
- There is no mandatory labeling regarding consumption and efficiency for luminaires.

In Switzerland there are two voluntary labels:

- For professional luminaires: MINERGIE® Label [3]
- For domestic luminaires: Topten

Discussion and prospects

Together with retailers, Topten and the University of Applied Sciences HTW Chur have taken a step and focus not only on the lamp, but look at how much light is actually coming out of a luminaire. Experiences from the past three years show that retailers and manufacturers are considerably interested in such information. The main benefits are firstly to gain information for buyers and customer service, secondly to get product data from independent measurements. With this article we hope to give clues and motivation to retailers on how to communicate efficiency and quality of domestic luminaires to their customers.

A test method and the declaration of efficiency for domestic luminaires should be regulated on a European level. Taking into consideration the characteristics of domestic luminaires, the test method should be simple and affordable. This article describes a first example of a measurement that gives relevant data in a simple way. A measurement in a goniometer would be desirable. It delivers data on the luminous flux that is easy to compare between all types of luminaires.

The following essential data should be available:

- energy consumption during use and standby
- luminous flux (lumen) or intensity of illumination on the use surface (lux)
- for luminaires with in-built LEDs: CRI and color temperature

We propose the following requirements for domestic luminaires:

- Standby consumption should be limited to 1 watt for luminaires with sensors or ballasts for dimming (in a second step to 0.5 watt). For luminaires without sensors or that are not dimmable, no standby consumption should be allowed.
- Luminaires for work tables and reading should be required to get 500 lux on an area of at least 0.13 m^2 or 0.07 m^2, respectively.
- For LED products, a CRI of minimum 80 should be mandatory.

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission's Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in two more European countries (www.topten.eu).
- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.
- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation - www.repic.ch) and SECO (State Secretariat for Economic Affairs - www.seco.admin.ch) who supports the build-up of Topten China.

References

[1] Indications from retailers

[2] Test of 14 LED Retrofit Lamps - English Summary of Test Results. PDF download at: http://www.topten.eu/english/criteria/selection_criteria_energy_saving_lamps.html&fromid=

Link to Swiss television show on the 01/11/2011 about the test of 14 LED retrofit lamps (in Swiss German): http://www.kassensturz.sf.tv/Nachrichten/Archiv/2011/01/11/Test/Was-die-neuen-LED-Lampen-taugen

[3] Complete list of professional luminaires with the Swiss MINERGIE® label, requirements and verification procedure (in German): http://www.toplicht.ch/

English information about MINERGIE®: http://www.minergie.ch/home_en.html

Prospects for LED and a change-of-stock model

Mats Bladh

Department of Thematic Studies—Technology and social change, Linköping University, Sweden

Abstract

What are the prospects for LEDs? Europe is in the middle of phase-out of inefficient lighting. Why is regulation necessary, considering that efficient technologies are cheaper in the long run? There are other efficient lighting technologies that can replace incandescent lamps, what is the role of LEDs?

The trouble with LED is that the supply for ordinary consumers is limited today. LED lamps can replace incandescent lamps only up to 25W at the highest, within a reasonable price range. Thus halogen and CFL lamps will probably replace incandescent during the phase-out. This will delay the diffusion of LED lamps.

In order to calculate the aggregate effects, the whole stock of lamps of all Swedish households has to be taken into account. Such a model looks at the change of stock, how fast is the replacement rate and in what direction change is taking. Can this stock-model be applied to other types of artefacts? If so, what can be learned from the phase-out of lamps?

A stock of energy converting artefacts changes through the scrapping of old and adding of new items. Each item has several characteristics, or quality aspects, of which energy use is just one. There is no a priori reason to believe that energy efficiency will increase. The advantage of the phase-out method is that consumer's purchases are coordinated and directed in one direction concerning one quality aspect, energy use. For other products weaker forms of coordination is used such as labelling and taxes on fuel. A prerequisite is an energy efficient alternative that is as good in other respects as those in the stock. If not, a phase-out would result in hoarding and end up as illegitimate.

What are the effects of the phase-out?

On 18 March 2009 the European Union decided to phase-out inefficient lighting technologies starting 1 September that year. In effect this is a phase-out of incandescent lamps beginning with 100 W incandescent light bulbs, and continuing with lower wattages and ending with a prohibition of 15 W in September 2012 (1). This means that new incandescent must not be sold, but it is also a phase-out of inefficient lamps in the residential stock of lamps, with a delay depending on hours of use and quality of lamps used.

We do not know so much about the lighting stock. The studies made so far are not representative of the whole household population. The number of households covered is small, from a statistical reliability point of view, due to the fact that data collection is cumbersome as the hours-of-use is essential information to collect. The most comprehensive study made so far, is that already mentioned by the SEA 2005-2008. Data from this source is shown in Table 1.

Table 1. Unweighted averages on Swedish household's use of electric lighting 2005-2008.

	Small houses	**Multi-dwelling houses**
Number of lamps	55.2	31.2
Wattage per lamp (W)	29.3	26.6
Hours-of-use per day and lamp	1.60	1.94
Number of households (000)	1,978	2,238
Electricity for lighting (TWh)	1.87	1.31
Lighting/all electricity (%)	22.7	19.0

Sources: (10), (13), (14). "Small houses" include detached houses and houses with two dwellings. "Multi-dwellings houses" often contain shops, offices and other non-residential spaces, but the main purpose is residential.

It must be emphasized that the real stock can be different. The sample is small in relation to the population of households, and the geographical distribution of the sample is quite narrow (concentrated to an area in the south-middle of Sweden including Stockholm westwards, “Mälardalen”). On the other hand data covers several types of households in regard to housing, age, number of people, etc., and it is very detailed comprising observations on each appliance (including each lamp) every ten minutes for a month or a year. So, data is accurate and contains a lot of information, but it is not representative. With this in mind, we can let data give us a hint of what the national consumption of electricity for lighting would look like. From data in Table 1 it can be calculated that there are 179 million lamps in total.

Table 2. The distribution on lamp types in Swedish households, and assumed lifetime and price level for each type. Per cent, hours, Euro.

Lamp type	Share, %	Life time, h	Price level, €
Incandescent	60.5	1000	1
Halogen	16.2	3000	4
CFL	13.1	7000	6
Fluorescent tubes	10.2	10000	6

Sources: (10), (15). Currency rate assumed: 10 SEK=1€. 1 USD ≈ 0.75€ in May 2010.

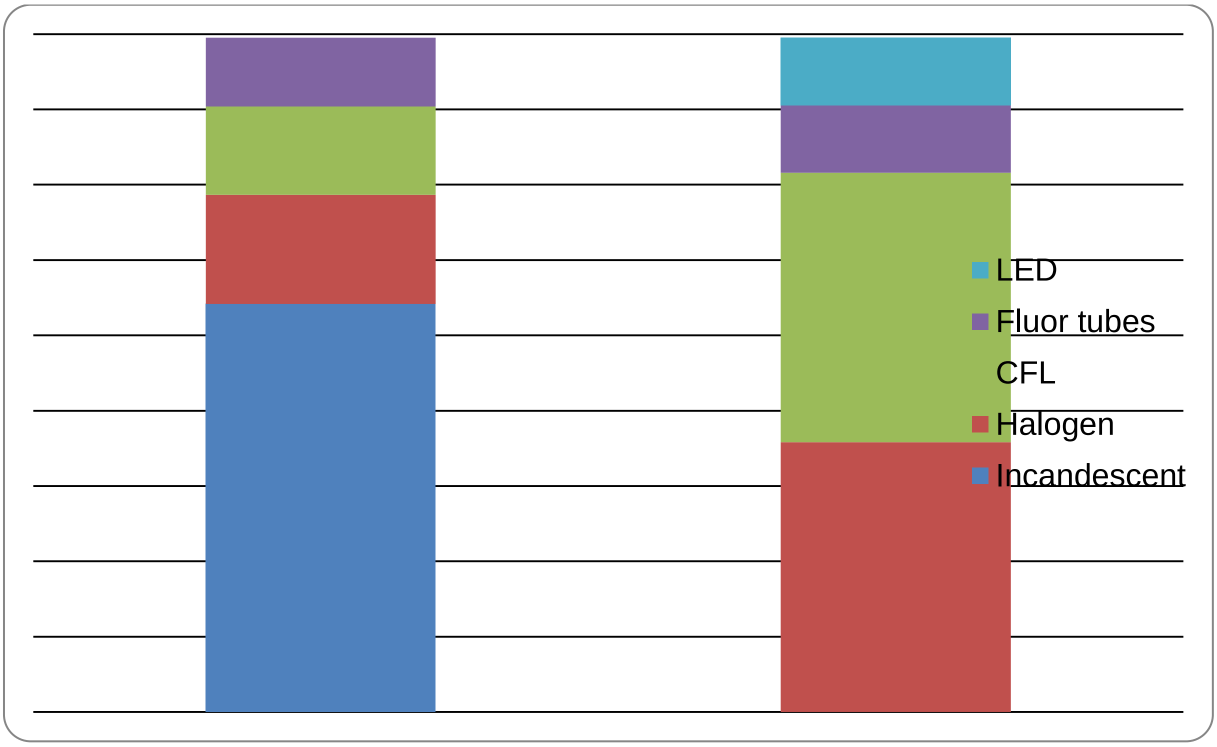
Lifetime and price level varies from one variant and from one brand to the other. Prices presented are common prices in stores and on the Internet in Sweden in May 2010. Life times used are common assumptions in the literature (6, 9). Assumptions on lamp’s life are necessary due to the secrecy of sales of lamps. *Belysningsbranschen,* a trade association for Swedish lighting manufacturers and lighting consultants, does not disclose any information on sales. However, in a press release from the SEA we are told that *Belysningsbranschen* said that “sales of incandescent lamps decreased with 36 per cent” in the autumn of 2009 compared to the autumn of 2008. Halogen lamps increased with 85 per cent and CFL with 90 per cent (15). This indicates that halogens and CFL will replace 108 million incandescent lamps.

Table 3. Economics of the phase-out.

	2010	2013
Replacement rate, %	43	13
Power per lamp, W	28	16
Electricity for residential lighting, TWh	3.2	1.9
Lamp sales, million Euros	113	108
Electricity sales, million Euros	483	281

With data presented in Table 2 it is possible to calculate the rate of turnover. Before the phase-out (with over 60 per cent incandescent lamps) the rate was 43 per cent per year. After the phase-out, assuming 0 per cent incandescent lamps, 40 per cent halogens, 40 per cent CFL, 10 per cent fluorescent tubes, and 10 per cent LED in the new stock, the rate becomes 13 per cent. Despite this decrease in the rate of renewal, the value of sales stays at approximately the same level, a small change from 113 to 108 million Euros—on the condition that prices remain the same. On the other hand sales of electricity will decrease quite significantly. When halogen, CFL and (to a lesser degree) LEDs replace incandescent lamps it can be estimated that the average wattage per lamp will decrease from 28 to 16, and total energy consumption for electric lighting will decrease from 3.2 to 1.9 TWh. If prices for 1 kWh are 0.15€ then income for electricity suppliers will decrease from circa 483 to 281 million Euros—a transfer from suppliers to consumers of about 202 million Euros.

Figure 1. Possible change of domestic stock of lighting in Sweden. Before and after the phase-out.



Sources: (10), (13), (14).

The problem for the future prospects for LED lamps is that the phase-out started with a LED supply limited to a low lumen range. As of Spring 2010 a consumer can find LED lamps up to 100 lumen only, at affordable prices. Brighter lamps are very expensive and seldom found in ordinary stores. It can be argued that LED lamps will appear in the coming years that are able to compete with halogens and CFLs. However, the CFL have the lead and will be bought during the phase-out. LED lamps can perhaps cover 10 per cent of the stock in the coming years, but will have to wait five years for halogen lamps, and ten years for CFLs, to be scrapped. However, this may be fortunate, as it gives manufacturers the time to develop LED modules acceptable to consumers.

These changes in the national residential lighting stock are based on certain assumptions described above. The real effects of the phase-out may turn out differently. However, one thing is for certain—the incandescent lamps will disappear within the next few years.

Path dependence and lighting

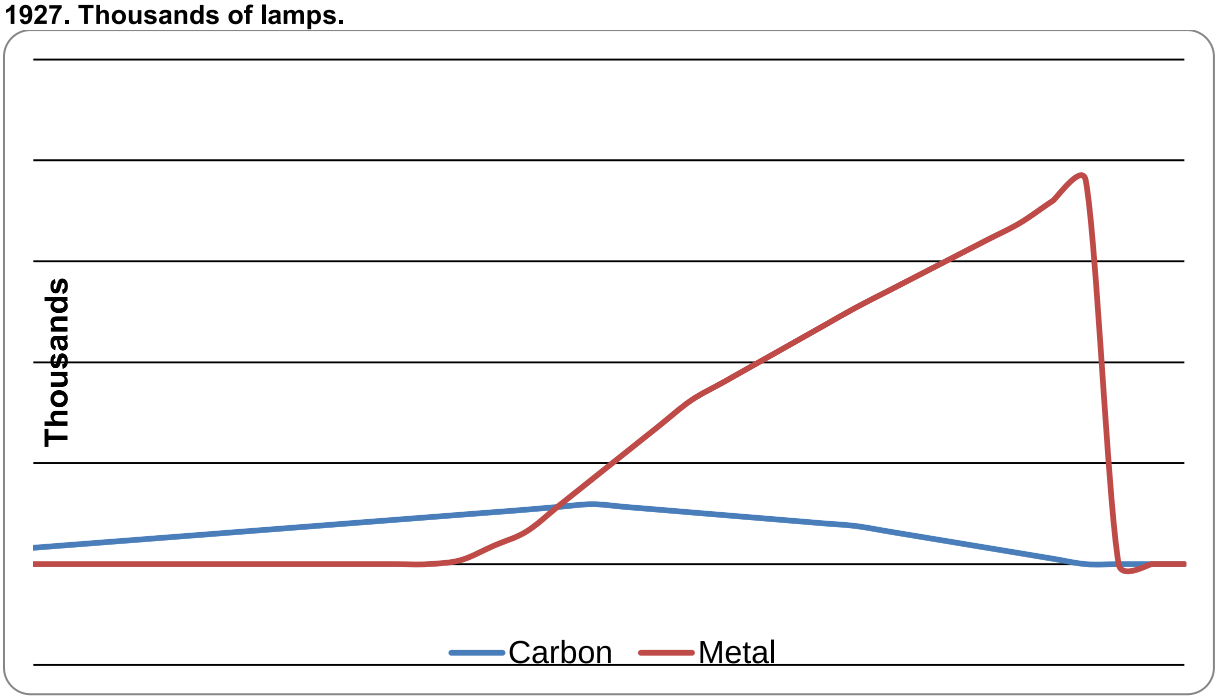
When we think of the stock of lamps in the homes of approximately 4.216 million households in Sweden, as it has been disclosed through the monitoring campaign initiated by the Swedish Energy Agency, we can see several types of lighting technologies beside each other. The main types are incandescent lamps, halogen lamps, fluorescent tubes, and compact fluorescent lamps. To this may now be added a small portion of LED-lamps. Why are the old still here?

Even though the halogen is basically an incandescent lamp it should be regarded as a different type. Because of its regenerative process it has a longer life, a higher efficiency, a whiter light and superior optical properties. The fluorescent tube is definitely a radically different lighting technology. It is not so obvious why we should consider CFLs as a special type. The CFL is a miniaturized fluorescent tube, either U-shaped or in a spiral, sometimes covered by a bulb. A CFL has built-in electronics and a size and sockets suitable for ordinary light-bulb fittings. What makes the CFL different is that it is intentionally made to replace the incandescent lamp, adjusted to the existing stock of luminaires. The necessity of such an adjustment indicates a sort of conservatism, or path dependence.

Path dependence means that both supply and demand follow old patterns. The theory is composed of two sub-theories, one explaining a branching of technical development where an inferior alternative wins over its competitor. The other is “lock-in”, which explains why the dominant design keeps its position as dominant despite superior alternatives. Lock-in is explained by cost advantages in production and advantages of habit in consumption. Path dependence does not mean that there is no change at all, rather that change follow a well-known pattern. Manufacturers tend to keep on manufacturing the kind of lamps that they have been manufacturing, and buyers tend to keep on buying lamps that they are using (3).

The incandescent light bulb is an old innovation. The original Edison incandescent lamp with carbonized filament had a very low rate of efficiency—only 2.6 lumen per Watt. It had an exclusive character and had limited success among ordinary households in competition with kerosene and gas until the metal filament was introduced in the early 20th century. In just a few years the number of lamps with tungsten filament outnumbered the older type in Sweden. While the Edison-lamp never sold more than 297,000 (1912), the new light bulbs sold in increasing numbers, reaching 811,000 in 1915 and 1,619,000 in 1925 (4). These new incandescent light bulbs were more efficient, about 12 lm/W, did not blacken and could be used for more hours (5).

Figure 2. Sales of carbon filament and metal filament incandescent lamps in Sweden 1895-1927. Thousands of lamps.



Source: (4).

Why did the metal filament lamp grow so fast? We do not know. Efficiency and life cycle costs may not have been decisive, it could just as well be that the smoked glass of the carbonized filament lamp made users dissatisfied as they experienced declining brightness over time. On the other hand, the Edison lamp may have prepared the ground, in terms of fixtures and outlets, without which expansion for the new types would have been more difficult.

The metal filament lamps marked a step upwards in efficiency. However, improvements in efficacy came to halt at this level—today it is still around 9–14 lm/W (6). Due to mass production the price could decrease, and due to acquaintance it became the standard lamp among householders. Later came the fluorescent and the halogen. Even though inventions and market introduction were made earlier, the fluorescent did not become common in Swedish homes until the 1970s, and the halogen even later (7). The efficacy of fluorescents has always been very much higher than that of incandescent lamps’, never below 30 lm/W, today in the range of 60–100 lm/W. Also halogen lamps have been more efficient, today ranging from 10-30 lm/W (8). The CFL, invented in the 1970s at General Electric, were introduced to the general public in the 1990s, but it is not until the 2000s that they have made any significant penetration (9). The efficacy of a CFL is lower than that of a regular fluorescent tube—60-70 lm/W, or so—but compared to the ordinary light bulb they replace they constitute a clear shift upwards in energy efficiency. Despite these newcomers in residential lighting technology the incandescent has kept its position as the most common light source.

Figures from the monitoring study performed by the Swedish Energy Agency 2005-2008 show that more than 60 per cent of all lamps in Swedish households were incandescent lamps. Halogen comprised 16, CFL 13 and fluorescent tubes 10 per cent (10).

Why this conservatism? When new more efficient lighting technologies appear on the market, why does not everyone buy them? One obvious barrier is the higher purchase price. Halogens, CFLs and LED cost more than an incandescent at the same lumen level. This discourages people to buy them despite the lower life cycle cost (purchase + use cost) of the more efficient lamps. What about habits? But habits can change. If habits do not change, what is the cause of that? One answer would be that habits have hardened in a lighting culture. The point is that the culture says what a good light is, and this cannot be changed by information.

A Nordic lighting culture

Harold Wilhite initiated a comparative study of lighting use in Norway and Japan. This was published in 1996 and has become a classic by now. The project team, with members from Norway and Japan, interviewed 18 households in Oslo and 16 in Fukuoka in the early 1990s. Astonishing differences was revealed in this comparison. While Norwegians wanted to create a cosy home the Japanese wanted brightness. Norwegian households preferred several shaded floor lamps, small table lamps and spot-lamps. While there were 10 lamps in a Norwegian living room there were only 2 or 3 in Japanese. Ceiling fixtures and fluorescent light were considered as absolutely inappropriate in a Norwegian living room, but were used in bathrooms and kitchens. The Japanese households, on the other hand, associated incandescent light with insufficient brightness, and often used fluorescent tubes fixed in the living room ceiling. In bathrooms several Japanese respondents said that incandescent lights were appropriate because they lighten up without delay (11).

Thus we can talk about a Nordic lighting culture where households use many small luminaires with a warm glow for the sake of a cosy atmosphere. The existence of this lighting culture was confirmed by a study reported to the European Commission. While the average number of lamps per household was 24 in the EU in 2007, the average was 42 in Sweden; The average wattage for incandescent lamps was 54 in the EU but 32 in Sweden, and for CFLs 17W in the EU but 8W in Sweden (12).

However, even cultures can change. The phase-out in EU (and in the USA 2012-2014) (8) will change lighting set-ups in many millions of homes in Europe and America. In the Nordic countries will this change dissolve the material base for the Nordic lighting culture? The absence of hoarding can be taken as a sign of weak habits and preferences, so that the lighting culture can disappear or change. However, it is only from September this year that 60W will disappear from the shelves–perhaps the reaction will come then.

The Nordic lighting culture, which had the warm glow of the incandescent lamp as a fixed point for the definition of the good light, is threatened. The question is whether lamps that get as close as possible to the light of the incandescent lamp will prevail in the long run, or if the Nordic lighting culture will radically change or disappear.

Monica Säter's study shows that test subjects preferred halogen before LED light sources (18). Nevertheless, subjects gave positive judgements on the LED-light in five out of nine cases and, surprisingly, Scandinavians were more positive to the LED-light than Europeans. This indicates that a Nordic lighting culture can change when the lighting stock changes due to the phase-out. Bladh (19) studied the acceptance of LED and CFL in one Swedish household. All incandescent light sources were replaced with either CFL or LED-lamps, as if the phase-out was carried out in a single stroke. Even though this household adhered to the Nordic lighting culture it accepted the new lights, including LED-lamps with a bluish light at the bed. Six months after the radical change of the lighting set-up, all new light sources were still there and they had no intention of return to the old lamps or replacement to halogen lamps.

A possible interpretation of these studies is that the Nordic lighting culture is solid but that it allows for other lighting technologies in niches, for specific purposes. In such a case we will see efforts among householders to restore the loss of the warm glow from many low-lumen lighting points. For LED-suppliers this means that the LED-technology has to be developed so that it brings a more yellow colour and with a suitable design.

Another interpretation would be that the Nordic lighting culture is weak and will disappear as its material foundation phases out. A third possible interpretation is that halogens and CFLs can be developed so that they satisfy the specific qualities of the Nordic lighting culture. In both these cases LED-lamps and luminaires will be reduced to a marginal role in the average Swedish residential lighting set-up. What eventually will be the outcome will be decided during the following years, when 60W and 40W + 25W incandescent lamps are phased-out, as these make up the core of the stock and are essential for the lighting culture. Hoarding or other reactions in the coming years indicate a need for new types of LEDs.

The phase-out solves one problem of path dependence in lighting, namely that it pushes consumers over the barrier of the higher price of more energy efficient lighting technologies. However, halogens and CFLs are not the best solutions, as lifetime is short compared to what LEDs promises and as CFLs contain mercury. Furthermore, the phase-out perhaps does not solve the other side of lock-in, that of habits and culture. A remedy would be a new LED imitating the light of the incandescent.

A model for interpretation?

The analysis above focus on the relative advantages of new items compared to those in the stock. This idea can be generalized to other technologies: other electric appliances, vehicles, buildings, even industrial machinery. A stock of lamps and luminaires changes through scrapping of old units and adding of new units, and this can also be said of freezers, cars and a lot of other technologies. From the perspective of promoting energy efficiency it is decisive whether units added to the stock is better than those scrapped, and this can be (and has been) a policy target. However, the example above shows that there are more to a lamp than just its level of energy efficiency.

Energy is never used directly but always by way of an artefact— a paper machine, a car, a dwelling, a luminaire and lamp. There are stocks of machines, vehicles, buildings and appliances that demand energy. These things are not only energy converters they also have other qualities important for the buyer and user. Kelvin Lancaster introduced the notion of “characteristics” of goods to economic theory (2). His point was that goods were not homogeneous but made up of several aspects, or qualities, or properties. A car, for instance, can be judged according to its energy use characteristics, but also according to its size, speed, weight, design, comfort etc. What energy conservation policies did was to raise energy to a more prominent position among the characteristics of products. Previously ignored or downplayed energy was more and more paid attention by manufacturers and users.

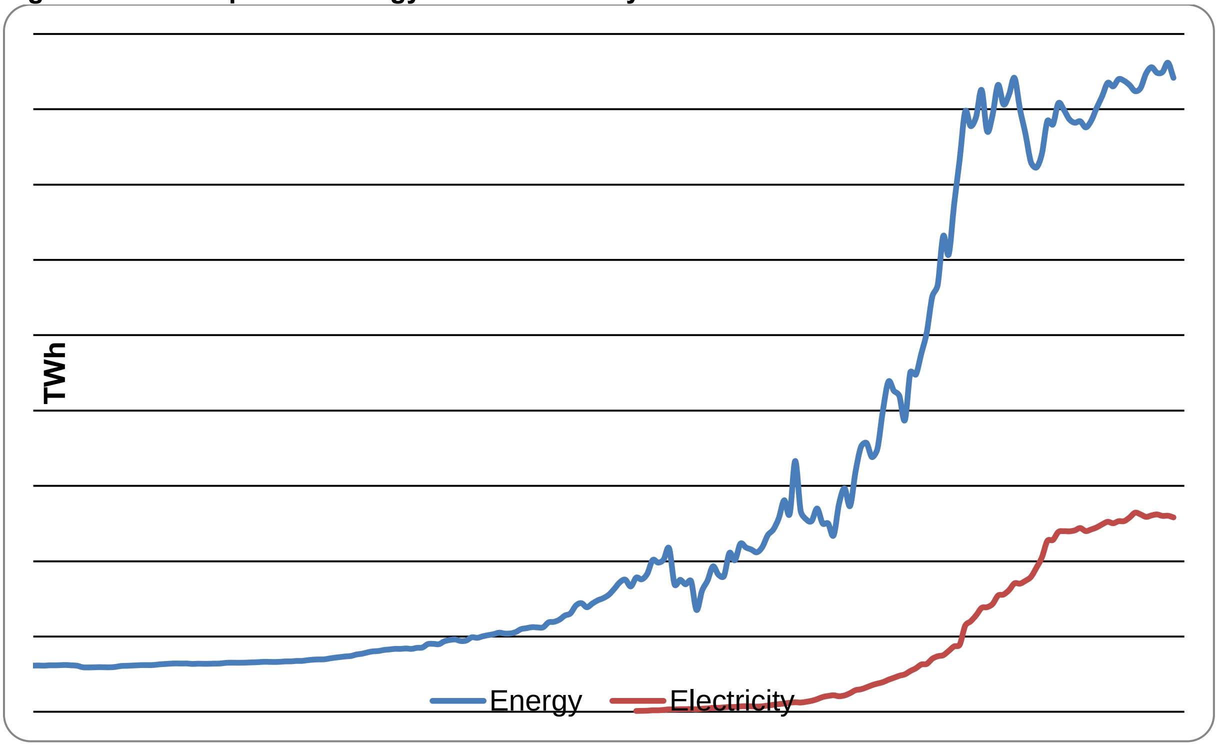
My proposition is that there are large stocks artefacts diffused all over society functioning as energy converters: Industrial machinery, vehicles, buildings, and electric appliances of different types. These stocks change slowly through the adding of new units and scrapping of old ones. Whether this change leads to higher energy efficiency or not is an open question because the renewal of the stock can follow a path-dependent pattern. I will show this with examples from Swedish energy history.

A growing attention to energy efficiency in the mix of characteristics

In the long-term perspective a change occurred in 1970s. At this point in time energy use stagnated in Sweden (and elsewhere in the industrialized world). In the mid 1980s even electricity consumption stagnated. These two long-term changes are of historical significance. Before the first and the second oil crisis in the 1970s energy use increased year after year incessantly as it seemed. For long energy efficiency was a non-issue, as prices decreased, both for electricity and for oil. Energy use could expand without limit it seemed. Then suddenly oil prices doubled as a consequence of OPEC price policy and oil embargos during the winter 1973–1974, and doubled again due to the shortages caused by the Islamic revolution in Iran and the war between Iraq and Iran 1979–1981. This hit hard on oil importing countries, and new policies were introduced. An era of conservation of energy began, and the use of energy became a matter of policy.

Concerning electricity supply, and specifically for Sweden, there was also a radical change. Erection of dams and hydropower stations for the purpose of distributing electricity to end-users—primarily industries, the state-owned railway organization and other big users but also householder's lamps—began in the early 20th century. As electricity is relatively efficient in comparison with other energy carriers, and possible to apply for many different end-use artefacts, consumption increased fast and steadily. High investment costs and economies of scale are associated with this technical system, prices and thus end-user costs for electricity decreased radically from the 1920s, and this reinforced the tendency towards rapidly increasing use of electricity. Investments in hydropower capacity were especially intense in the 1950s and 1960s, when dams, machinery and cables became bigger, more powerful and longer than ever before. At this point in time, however, hydropower ran into resistance from river savers, and the protests gained mass support and became an issue in the political system. In 1970 the fight about one of the few unexploited rivers was won by the river savers, and it was later decided by the parliament not to exploit the remaining four untouched rivers. In effect, this meant that hydropower capacity came to a halt.

Figure 3. Consumption of energy and of electricity in Sweden 1800–2008. TWh.



Sources: 1800–1969 (16); 1970–2008 (17).

Also nuclear power came to a halt, albeit at a later date. After some preparatory efforts Swedish electricity supply companies began investing in nuclear power in the 1960s, and the first reactor were put in operation in 1972. However, a critique of nuclear technology appeared, among others from the Nobel laureate in physics, Hannes Alfvén, who convinced one of leaders of a political party to oppose the operations of nuclear reactors already built and under construction. This party came to power in 1976 and this initiated a heated debate around nuclear power and energy policies in general. After the Three Mile Island accident the debate came to a climax before a referendum in 1980. Even though the outcome of this referendum is a matter of interpretation (and still is) the critique influenced prospects of further investments. After 1986 no reactors have been installed, while two have been shut down, so to the halt in hydropower was now added a halt to nuclear power.

In hindsight a change occurred in the 1970s that has lasted and even been pronounced in later years. For long energy had been a supply issue, where the main problem was how to satisfy the need for cheap energy in industry and transport, preferably without importing fuel from abroad. But now the use of energy came to attention, at first as immediate responses to price hikes in oil. This change was not a clear-cut shift of attention from supply to use. Rather that attention was given to both sides, and still is, albeit climate change has pushed energy efficiency more to the forefront. It must be concluded that when energy supply became scarce, energy efficiency came to the fore, when supply was abundant efficiency at the user end was a non-issue.

Prices for electricity and oil have been rising in the long-term since the 1970s, not the least because of taxes on energy. When costs are rising one would expect that users of energy—households, industries, businesses—change their installations and behaviour in order to compensate for rising costs. For sure, overall improvements in energy efficiency have been made, but there are also tendencies in the opposite direction, of the use of more electric appliances, heavier cars, low cost air travel, etc.

Conclusions

The prospects for LED-lamps were considered to be one of delay. As halogen and compact fluorescent lamps already are available in stores today, they will replace incandescent lamps scrapped from the stock. The supply of LED-light, at affordable prices, is limited and cannot take the role of replacement. It is possible that LED can be the second generation of energy efficient lighting, but then new LEDs will have to compete with a slow-changing lighting stock, and without support a phase-out regulation.

The phase-out solves one problem of path dependence in lighting, namely that it pushes consumers over the barrier of the higher price of more energy efficient lighting technologies. However, halogens and CFLs are not the best solutions, as lifetime is short compared to what LEDs promises and as CFLs contain mercury. Furthermore, the phase-out perhaps does not solve the other side of lock-in, that of habits and the Nordic lighting culture. A remedy would be a new LED imitating the light of the incandescent.

The analysis the phase-out of inefficient lighting technologies focus on the relative advantages of new items compared to those in the stock, and that there are counteracting tendencies due to path dependence in use. This idea can be generalized to other technologies: other electric appliances, vehicles, buildings, even industrial machinery. A stock of lamps and luminaires changes through scrapping of old units and adding of new units, and this can also be said of freezers, cars and a lot of other technologies. From the perspective of promoting energy efficiency it is decisive whether units added to the stock is better than those scrapped, and this can be (and has been) a policy target. However, durables are composed of several “characteristics” (Lancaster, 1966), of which their energy converting aspect is one. Whether scrapping and replacement in stocks of such energy converters improves the overall level of energy efficiency is an open question. Other characteristics than energy can be more important for the user. A change-of-stock model captures this and can possibly be used as frame of analysis on all energy converting end-use technologies

It was shown in this paper, through historical data, that a break in the trend of energy consumption occurred in the 9170s. This can be interpreted as a growing attention towards efficiency in use beginning with the first oil crisis. The energy characteristic was given attention from 1970s on, when man-made scarcity of oil induced a change in policy from supply to conservation.

References

(1) European Commission, 2009, ”Commission Regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps”. http://eurlex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Regulation&an_doc=2009&nu_doc=0244 (downloaded 2009-10-06).

(2) Lancaster, K., 1966, ”A new approach to consumer theory”, *Journal of Political Economy,* April 1966, vol. 74, issue 2, p. 132–157.

(3) David, P. 2007, “Path dependence: a foundational concept for historical social science”, *Cliometrics,* 1: 91–114.

(4) Körner, F., 1928, *Sveriges elektricitetsverksindustri.* Stockholm: Svenska Elektricitetsverksföreningen, p. 55.

(5) Nordhaus, W. D.,1997, ”Do Real-Output and Real-Wage Measures Capture Reality? The History of Lighting Suggests Not”, *The Economics of New Goods.* Edited by Timothy F. Bresnahan & Robert J. Gordon. The University of Chicago Press, p. 29–70.

(6) Starby, L., 2006, *En bok om belysning.* Stockholm: Ljuskultur, p. 163, 168, 225.

(7) Garnert, J., 2009, ”I nytt ljus”, *Fokus,* August 2009.

(8) Smil, V., 2005, *Creating the Twentieth Century. Technical Innovations of 1867–1914 and Their Lasting Impact.* Oxford UP, p. 42f.

(9) Held, G., 2009, *Introduction to Light Emitting Diode Technology and Applications.* Boca Raton: CRC Press, p. 82, 90.

(10) Zimmerman, J.P., 2009, *End-use metering campaign in 400 households in Sweden. Assessment of the potential electricity savings.* Enertech. Eskilstuna: The Swedish Energy Agency.

(11) Wilhite, H., Nakagami, H., Masuda, T., Yamaga, Y., Haneda, H., 1996, “A cross-cultural analysis of household energy use behaviour in Japan and Norway. *Energy Policy,* 24:9, 795–803.

(12) Van Tichelen, P., 2009, *Final report. Lot 19: Domestic lighting.* Study for European Commission DGTREN unit D3. <http://www.eup4light.net/assets/pdffiles/Final_part1_2/EuP_Domestic_Part1en2_V11.pdf>, downloaded 2010-03-01.

(13) Öfverholm, E. 2009, sheet with data from the monitoring study performed by the Swedish Energy Agency.

(14) “Antal hushåll (HEK) efter hushållstyp, boendeform och tid” referring to 2006. Extract from database, Statistics Sweden, http://www.scb.se, downloaded 2008-11-04.

(15) “Hushållen tycker att energieffektiv belysning är bra”, press release from the Swedish Energy Agency, 2010-04-28.

(16) Kander, A., 2002, *Economic growth, energy consumption and CO_2 emissions in Sweden 1800–2000.* Lund Studies in Economic History 19. Lund University.

(17) *Energiläget i siffror 2009.* Eskilstuna: Energimyndigheten (The Swedish Energy Agency).

(18) Säter, M., 2010, ”User Responses to Energy Efficient Light Sources in Domestic Homes”, in New Lighting–New LEDs. Aspects on light-emitting diodes from social and material science perspectives. Editors Mats Bladh & Mikael Syväjärvi. http://liu.diva-portal.org/smash/record.jsf?pid=diva2:360257

(19) Bladh, M., 2010, ”Energy efficient lighting meets real home life”, *Energy Efficiency,* 4 (2011), 2, 235–245.

Increasing customer acceptance of energy-efficient lighting

Christian Merz

Director Sustainability OSRAM GmbH

Abstract

Efficient lighting is a crucial element in a strategy for combating climate change. It offers significant savings and is relatively easy to implement. Legislation has been passed and is being considered to phase out inefficient light sources. However, lighting is also a significant factor for our quality of life, and thus in the focus of consumers.

Technically, alternatives abound - be it well-known compact fluorescent lamps, halogen alternatives or LED light sources. Especially LED lighting offers a multitude of advantages that more than offset what consumers perceive as disadvantages of energy-saving light. LEDs epitomise these new possibilities – using colors to create light moods at home and thus increase the quality of life for users, or making use of their small size to light a room beyond the traditional ceiling light outlet.

But – lighting a home and making the choices best for each light application has not become easier for the consumer. To increase acceptance and even enthusiasm for new light sources, several approaches need to be tackled simultaneously, and lighting companies play a key role. We are stepping up our efforts at educating customers and our consumers in the application and advantages of efficient lighting. Trainings for professionals are available – many at only minimal cost. End-consumers have been approached in malls or DIY stores to acquaint them with new products. All these experiences show –with the right approach, consumers will reach the consensus that energy efficient lighting is not only a necessity mandated by Brussels, but an exciting new opportunity.

Introduction

Potential of efficient lighting and related legislation

Artificial lighting consumes a considerable amount of energy - approximately 19% of end-use electricity worldwide, or about 2,4% of the worlds energy demand. A 2005 study by the IEA estimated a total use of 2651 TWh [1], a value comparable to half the electricity consumption of the European Union. A breakdown of different lighting technologies reveals that nearly 70% of this electricity is consumed by technology for which more efficient alternatives exist – today! At OSRAM, we estimate that by implementing more efficient light sources and intelligent light management systems, 50% of the electricity used today could be saved, resulting in savings of over 650 million tons of CO2.

Obviously, this fact has been recognized by legislators worldwide, with the phase-out of inefficient light sources being discussed, or having been moulded into law, in many countries worldwide. In Europe, the European Regulation (EC) 244/2009 [2] with Amendment 859/2009 [3]also known as Domestic [Lighting] Implementing Measure - DIM 1 - governs the phase out of inefficient non-directional light sources in Europe, while Regulation (EC) 245/2009 [4] with Amendment 347/2010 [5] (also known as: Tertiary Lighting Implementing Measure - TIM) concerns itself with professional light sources, like lamps for street- and office lighting.

Currently, further European Legislation is under discussion, relating to directional light sources (DIM 2). While the debate is ongoing (possibly, a conclusion will have been found by the time of the conference in May), the European Lamp Companies Federation (ELC) has put forward an industry position that calls for:

1. A phase out of standard incandescent reflector light bulbs.
2. A raising of efficiency standards for line voltage halogen reflector light sources beyond today's technology – but in line with R&D roadmaps.

3. In low voltage (12 V) halogen reflector lamps, allowing only efficiencies achievable with the best available technology to remain on the market.

Why legislation is not enough

If all these legislative efforts are considered, it could be assumed that there is no alternative to a substantive shift from inefficient technology to modern lighting; that there is little left to do to ensure that consumers use the most efficient lighting in their homes. However, lighting is also a significant factor for our quality of life, and the phase-out has been the subject of considerable criticism by consumers and consumer advocacy groups. Consumer's experiences with some of the new alternatives have not all been positive, and some are unsettled by media reports citing dangers of energy saving lamps. Even some Members of the European Parliament have called for a repeal of the phase out of incandescent lamps. In order to maintain the momentum/support for energy efficiency laws in Europe, and to encourage other countries to adopt similar legislation, a simple 'ban-and-forget' thus strategy seems ill-suited; efforts must be made to convince customers of the benefits of modern lighting.

Efficient Lighting Technologies & Customer Education

A great variety of alternatives exist for those lamps that are being phased out, all of them having distinct advantages and some disadvantages. Especially as most of the discussion revolves around a direct replacement for standard line voltage incandescent lamps, several very important advantages are often forgotten.

Halogen Lamps

For consumers sentimental about no longer being able to buy 'their' incandescent lamps, halogen lamps are one of the simplest solutions. Line voltage lamps now exist with halogen burners to echo almost all shapes of incandescent lamps. As they also produce light with a tungsten filament, they have the same Color Rendering Index (CRI) of 100% as do incandescent lamps. Technically, this is the most important argument for halogen technology. From a consumer point of view, they also have relatively low investment costs – around double the price of incandescent lamps, but typically also offer twice the lifetime. Halogen lamps can be disposed of as common household waste.

Halogen lamps also include the 12 V low-voltage types. With modern technology (such as infra-red coatings and special gas fillings), these lamps can reach double the lumen/Watt efficiencies of incandescent lamps, provided they are operated with a low-loss electronic control gear. The 12 V technology not only allows comparatively efficient light sources, but is also not dangerous to the touch. Thus, 12 V systems allow for unprecedented options concerning luminaire design.

Unfortunately, these advantages come at a cost in terms of climate protection – halogen line voltage lamps are typically only about 30% more efficient than incandescent lamps, and thus far removed from the best in class in terms of efficient light production. Nevertheless, they will continue to be an important element in domestic lighting for several years to come, and remain an important element for customer choice.

Fluorescent lamps – especially compact fluorescent lamps

Compact fluorescent energy-saving lamps with integrated electronic ballasts (CFLi) have become a symbol of climate protection with lighting. Almost all quality CFLi offer around 80% energy savings compared to incandescent lamps. Beyond this however, there are a multitude of differences, leading to considerable confusion and criticism from consumers. Educating consumers on these differences is one of the key points in increasing customer acceptance of energy efficient lighting today. The main issues are:

- End-consumer price: CFLis can be found in discount stores and shops for lighting experts, and are offered at retail prices between 1€ and over 20€. These price differences are partly on account of genuine differences in technology and quality, as can be seen in the next points.

- Life-Time and switching cycles: Almost all CFLi will have a rated life considerably longer than incandescent lamps. Typical values for quality lamps are 6 000 to 20 000 hours. For some lamps, this rated value may decrease significantly depending on the number of switching cycles the lamps are subjected to. A major influence on the life-time of the lamps is the technology of the built-in control gear and the quality of its electronic components. Switching on any discharge lamp such as a CFLi is 'stress' on its components. This can be minimized, i.e. by preheating the electrodes prior to starting. So while some lamps are indeed unsuited for use in applications with frequent switching – such as stairwells, other lamps are engineered to offer nearly unlimited switching cycles.

- Run-Up Time: a common cause for complaint are excessive run-up times, i.e. the time a lamp requires before reaching its rated light output. For some lamps, this may be up to several minutes. These times can also be influenced by electronics, but also by the type of mercury dosage – lamps using a mercury amalgam technology will take considerably longer to reach a high light out put.

- Color temperature and color rendering: The light from compact fluorescent lamps is different – both from natural daylight and from the light of incandescent lamps. This relates to color rendering – i.e. how naturally a color appears under artificial light. Typically, CFLi reach 70% to 80% CRI., depending on the mixture and quality of the fluorescent phosphors that are used in the lamp. It also relates to color temperature, expressed in Kelvin. Typical values in lighting technology reach from 2500 K (warm white, appears reddish in direct comparison) to 6500 K (cool white, similar to midday-daylight). The preferred light color varies by region, northern countries preferring warm-white, and countries in hotter climates preferring cool-white.

- Dimmability: fluorescent lamps can be precisely dimmed with appropriate electronic control gear. However this dimming mechanism has little to do with common household dimmers designed for incandescent lamps, which basically switch off the electricity for a portion of the time. The engineering challenge is to build control gear which 'interprets' the power it receives from the dimmer and to supply the lamp appropriately. Thus, CFLi which are dimmable with household dimmers require very complex and costly built-in control gear.

- Mercury and recycling issues: As discharge lamps contain mercury to operate efficiently, they must be disposed of properly and recycled according to the European WEEE Legislation [6]. This has been implemented throughout Europe, but more customer awareness is necessary to reach higher recycling quotas.

Obviously, CFLi are offered not only in many shapes and sizes, but also with different technologies depending on the requirements of the application of the customer. However, buying the right lamps has become more complex for the end-consumer. A main challenge for increasing customer acceptance of this efficient technology is thus education and better information on the pros and cons of different lamps.

Note: although relatively uncommon in domestic lighting, professional luminaires and lighting installations using non-integrated CFL (CFLni) or linear fluorescent lamps can also play a large role in modern efficient lighting, and the technical possibilities, especially concerning electronic control gear are much easier to realize. Here, luminaire manufacturers and light-designers or interior architects play a major role.

LED-Lamps and LED Systems

A recent development in domestic lighting are LED lamps as retrofits for incandescents. High-quality products that can adequately replace up to 60 W incandescent lamps are now finding their way onto the shelves of retailers, also offering 80% savings. LEDs have very long life-times (from 25 000 to 50 000 depending on the thermal management, but regardless of switching cycles), and contain no mercury. LED retrofits are set to relegate CFLi to a transition technology in the next decade. At present however, they have not yet found their ways into households in sizeable numbers. A large barrier for end-consumers is the price tag. The newest lamps typically have retail prices above 30€, although economies of scale will bring this price down considerably in the near future. At present, they have the same issues concerning color rendering, color temperature and dimmability as CFLi – quality comes at a cost. They are also covered by European WEEE Legislation, because of the electronics necessary for their operation.

However, packaging LEDs into products meant to resemble incandescent lamps does not realize their full potential –by far. The following factors show that LEDs can be used much more appropriately in new LED Systems

- Size and operating voltage: the actual LED light engine is very small, and typically operates on voltages under 5 V. This allows a multitude of possibilities in design – using several small light engines can thus produce a more homogenous glare-free lighting effect perfectly suited to a specific task.

- Directional light: LEDs generally emit light only to one side – typically in a 120° cone. Luminaires built with this in mind can fulfill a lighting task much more efficiently than those using a traditional lamp, as no reflector is needed.

- Color: LEDs can be made to produce almost any color of light, and by separately driving different color LEDs in a mixed array, light change effects can be produced easily. A common implementation of this capability is seen in so-called architainment applications – a modern lounge where the light ambience passes through all the colors of the rainbow is an application most of us can relate to. Such RGB-Applications are also part of the first consumer products in this area. But using color in LED lighting can have much more practical applications as well, and considerably increase our quality of life at the same time. By using predominantly efficient cool-white LEDs, but adding some red LEDs to achieve a warmer light color, a room can be lit in a comfortable warm-white light. However, the mood of the room can be changed in an instant, and a daylight effect conducive to higher levels of alertness achieved.

It thus becomes apparent that using LED to make retrofits for incandescent lamps ignores a large part of the potential that this new technology has. If sufficient effort is made to make luminaires and lighting solutions that make use of these new opportunities, consumers will adopt this new technology – not for the sake of its efficiency, but for the additional advantages that they have.

Organic LEDs

Organic LEDs are the next important development in lighting technology, offering light diffusely produced over large surfaces. Imagine the entire ceiling of a room providing diffuse, glare-free light – the same effect now produced comparatively inefficiently by using high-wattage wall and ceiling washers. However, while organic LEDs are now available in small quantities, and special purposes, they are not yet available to consumers in sufficient quantities to make a significant impact.

Increasing Customer Acceptance

Essentially, increased customer acceptance of efficient lighting in domestic environments will require a two-pronged approach. Professionals must be aware of all the possibilities and options available with efficient lighting in order to set new trends, and consumers must be informed about the choices they have today. OSRAM is well positioned on both these approaches

Efficient Lighting for Professionals

Obviously, many different professionals play part in the way we light our homes, and they must be approached according to their different needs and basic knowledge. Consider the following:

- Architects, Interior Designers and Building planners: Light offers a multitude of exciting possibilities when incorporated into buildings – spectacular showcases stand in tribute to this fact. However, an important target group are also those architects that build the gross of residential buildings. If planners move away from the traditional 'one-outlet in the middle of the ceiling', or architects incorporate design elements like ledges that allow for different approaches to lighting, the next generation of buildings will be lit quite differently. Well designed and well-lit houses will also provide examples that a large portion of the public can aspire to copy.

- Electricians: Modifying lighting requires work on electrical installation, and this should only be done by qualified electricians. So it is obvious that if you are considering changing the lighting in your home, you will consult an electrician beforehand – and he may well give you some ideas on modern and efficient lighting.

- Luminaire Manufacturers: The most inexpensive way to design a luminaire is to use a standard screw or bayonet type base – leaving the choice of an energy efficient lamp to the consumer, but simultaneously limiting it to an incandescent lamp retrofit. If luminaire manufacturers fully understand the new design possibilities offered by modern lighting technology, more luminaires will appear on the market using such elements – and the consumer will switch to efficient technology on the basis of other advantages.

Events and Information for Professionals

OSRAM seeks to approach professionals in a variety of ways. But as it is essential for them to gain hands-on experience with modern lighting, participation in specially conceived events has shown to be a powerful driver. Some examples include:

- Cooperations with the roadshows of partners, i.e. electrical installation suppliers: Here, lighting is just one facet shown in the context of modern electrical building technology.

- LIGHT on Site: an international event for architects and lighting professionals showing cutting edge technology in lighting design.

- PlanLIGHT: A special one-day seminar for lighting planners and architects mainly carried out in Germany.

- Building KnowLEDge: Over 20 Half-Day events in all of Europe, free of charge for the participants. Focus areas are LED-Basics, light-planning with LEDs, intelligent light and building management systems.

Better Information for Consumers

Consumers have long been targeted by different kinds of media – from advertising to information on the internet. A good example is the OSRAM web-based tool for finding energy-efficient lamps to replace those currently in use. Under www.osram.com/light-a-home , consumers can identify the type of lamp they need to replace and see different options for doing so. The tool calculates the amount of energy they save, translating this into money and CO2. But all these approaches require for the customer to become active on his own. To proactively approach the consumer OSRAM is now implementing three new approaches:

- Retail Staff Training: Special seminars are provided for the sales staff of retail outlets, as our experience has shown that untrained staff is unable to provide consumers with enough information to help them make a qualified choice. Over 2000 people throughout Europe have been trained so far.

- Mall Events: a special display was designed for 18 one-week stops at large shopping malls, mainly in Germany and Poland. The display is specifically geared toward consumers, and provides answers for the most frequently asked questions. New products showing the additional possibilities of LED-Lighting are also on display. The stand is manned by at least four specially trained consultants to address and issues the consumer may have.

- Power Sellers: Staff specifically trained on energy-efficient OSRAM products is provided to retail outlets. They relieve the regular sales staff and are able to field any questions consumers may have. The concept is presently being rolled out in 10 European countries, with thousands of assignments in the respective countries.

An additional advantage of this hands-on approach to consumers is the direct feedback received from consumers. This is fed back into product management and allows OSRAM to fine-tune its approach to further increase customer acceptance of efficient lighting

Conclusion

Summing up, it has been clearly shown that:

- Different lighting technologies have distinct advantages and disadvantages.
- Halogen lamps demand little consumer education since they have very similar characteristics and advantages as incandescent lamps, including a low end-consumer price. The energy saving potential is though far removed from the best in class of other technologies.
- CFLi differ in various characteristics from incandescent lamps. Educating consumers on these differences is one of the key points in increasing customer acceptance. CFLi offer a very big energy saving potential (around 80% compared to incandescent lamps).
- LED lamps offer an equal or bigger energy saving potential than CFLi. With both technologies, quality though comes at higher purchasing cost. LED lamps share some but not all of the issues of CFLi, plus they offer new advantages that exceed incandescent lamps. To fully profit from these advantages, it is necessary to consider luminaires or even whole lighting installations, instead of limiting the choice to the lamp only.
- OSRAM has made good experiences with proactively educating electricians, architects, luminaire manufacturers and consumers, and benefits from the direct feedback. All these actors are important to promote the best technology for each purpose, so the advantages of energy saving lighting are fully available for consumers.

Efficient lighting is an important part of Europe's transition to a low carbon economy. While legislation serves to phase-out inefficient products, it is important to augment such legislation with positive impulses for consumers. Only then will we be able to maintain the momentum of this shift and build a more sustainable future together.

References

[1] Waide, P and Satoshi T. *Light's Labour's Lost*. Energy Agency (FR), 2006. Can now be downloaded at www.iea.org

[2] COMMISSION REGULATION (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps. Can be downloaded at: http://europa.eu.int/eur-lex/

[3] COMMISSION REGULATION (EC) No 859/2009 of 18 September 2009 amending Regulation (EC) No 244/2009 as regards the ecodesign requirements on ultraviolet radiation of non-directional household lamps. Can be downloaded at: http://europa.eu.int/eur-lex/

[4] COMMISSION REGULATION (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council. Can be downloaded at: http://europa.eu.int/eur-lex/

[5] COMMISSION REGULATION (EU) No 347/2010 of 21 April 2010 amending Commission Regulation (EC) No 245/2009 as regards the ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps. Can be downloaded at: http://europa.eu.int/eur-lex/

[6] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). Can be downloaded at: http://europa.eu.int/eur-lex/

Standardization of User Interfaces for Lighting Controls

Bruce Nordman[1], Jessica Granderson[1], Kelly Cunningham[2], Katherine Wu[2]

[1]Lawrence Berkeley National Laboratory
[2]California Lighting Technology Center

Abstract

Progress in energy efficiency has required pursuing a wide variety of approaches, methods, and disciplines. A recent addition is improving user interfaces, a technique which enables energy savings not otherwise possible. User interfaces enable and structure communication to and from devices. When this communication degrades, there is increasing loss of amenity to the user – in not getting the energy services they want – and increased energy use – through providing more than is wanted. Standard user interfaces can help ensure the best possible outcome for communication.

This paper presents a summary of initial research on content for a global standard for lighting control user interfaces. A review of potentially relevant industry standards confirmed that there is no existing standard that covers this topic area, but many standards are related, including those covering symbols, indicators/actuators, generic user interface issues, accessibility, user interface content common to other energy concerns, and terminology. We surveyed many existing products, ranging from simple switches to products with many buttons and finally to some that use graphic display technology. We describe a classification scheme for the entire 'form' of the control, catalogued the use of specific "elements" in the interfaces, and extracted topics ("concepts") that embody meaning and are represented in collections of interface elements. Finally, we consider plausible paths forward to creating content suitable for a global standard.

Introduction

Example

Across the landscape of commercial and residential lighting controls, one often encounters interfaces that look the same but are bound to control systems with very different functionality, and therefore effect a wide diversity of system responses. The converse is also true: one often encounters different interfaces elements that effect precisely the same response or functionality. These concepts are illustrated in Figure 1, which shows from right to left, interfaces that comprise:

Figure 1: Six interfaces for dimming control that use different conventions and elements to communicate functionality and to effect control options.

- A single slider, where actuation upward is to brighten, and actuation downward is to dim
- Arrow buttons, where actuation upward is to brighten, and actuation downward is to dim; the buttons are combined with LED lights to indicate the brightness level
- No elements to suggest dimming capability or brightness level
- A light bulb icon paired with an 'increase' symbol and indicator light; actuation to the right brightens and actuation to the left dims
- An icon with the letter 'M' paired with text to indicate on/off status, and an 'increase' symbol; actuation to the left brightens actuation to the right dims
- A light bulb icon paired with text to indicate on/off status; numbers indicate brightness level; actuation

to the right brightens

•

Both residential and commercial lighting controls are becoming increasingly complex as technology advances, and as energy efficiency becomes a more critical aspect of building control systems. Industry and research and development trends indicate that tomorrow's lighting control systems will feature more sensors and automation, a higher degree of networking, and will accommodate more complicated control paradigms such as demand-responsive load shedding, and the integration of lighting with shading and HVAC systems.

If users are unable to understand lighting control interfaces, they are also unlikely to comprehend the intended system design and operation, or appropriately modes of interaction. Lack of comprehension is a problem itself, but also more increases energy use and/or delivers non-optimal lighting quality.

Standardization of the elements and conventions in human-machine interfaces has been successful in increasing user understanding and reducing operational errors in many areas including automobile dashboards and controls, aviation, and alpha-numeric assignments for telephone keypads [SAE, 2010]. It is therefore reasonable to expect benefit from some level of standardization in the design of user interfaces for lighting control.

The objective of this study was to determine the state of user interfaces for residential and commercial lighting control, and ways in which standardization might be applied to improve them. This paper reports findings from three primary activities:

- Review of existing standards, committees, and organizations and high-level areas of coverage that are most relevant to lighting controls
- Survey of existing lighting controls and development of a framework to characterize the forms and elements that they comprise
- Identification of concepts, mappings and associations, and existing standards that could be leveraged for the development of a user interface standard

The remaining sections of this paper detail our findings in each of those three areas, followed by conclusions and recommendations for future development of a standard. This paper is adapted from lengthy report [Nordman et al, 2010] on the topic and so necessarily presents only key points or summaries, not the full detail of our research.

Background – User Interface Standards

An earlier use of UI standards for energy efficiency purposes (possibly *the* first) was for power control of electronic devices [Nordman, 2004]. This research was embodied in a standard, IEEE 1621 [IEEE, 2004] and is strongly recommended in many Energy Star specifications. That work focused on terms, symbols, colors, and an overall metaphor for low-power modes (sleep).

In the research on power control, a range of conventional standards (national and international), informal guidelines, and manuscripts on good user interface design were found to be relevant. There was no existing standard which directly addressed the topic at hand, though many standards addressed aspects of the topic and so needed to be taken into account. A home for the standard also had to be found. We used the same overall approach for this project.

The existing relevant standards and committees fall into several categories: graphical symbols, indicators and actuators, safety, accessibility, and terminology generally. Existing committees and standards are almost always "horizontal" — apply to all applications but cover only a single interface element in isolation — or provide only vague, general principles for user interface design. This is in contrast to "vertical" standards which specify many or all aspects of a particular application. Vertical user interface standards are rare. Apart from IEEE 1621, the only other one we are aware of is a standard for vehicle controls [SAE, 2010]. The content in this is familiar to anyone who drives an automobile, covering nearly all the symbols found on the dashboard, as well as color meanings, and guidance on applying the standard in practice. Thus, this standard is an important example in being vertical, covering multiple types of elements, in the amount of content it covers, and that it is intended for such a wide audience. It also is important being successful, and in addressing a buildings-like topic, as a vehicle is in many respects just a building on wheels. Our goal is to create a vertical standard for lighting control *elements*. Many aspects of lighting controls, e.g. placement on a wall, size of keys, etc., are well outside our scope. In addition, lighting controls only used by professionals (e.g. theatrical) are also outside our scope.

Lighting Standards

Lighting research occasionally touches on user interfaces, in deployment of specific installations of controls, but the UI is generally an *ad hoc* implementation detail and not understood in the standards context. Research on commissioning of controls sometimes touches on how this is done mechanically, which has a user interface dimension, but is not particularly informative as to how people generally experience controls.

Lighting research for energy efficiency typically focuses on improving the physical efficiency of equipment and functionality of controls (essentially, the interface between the control and the light source). Those involved are accustomed to these approaches and able to make progress without considering user interfaces. Digital controls are expected to save significant energy through occupancy, daylighting and scene controls. Setting up and dealing with this increased functionality requires sophisticated user interfaces and coping with mounting complexity.

Standards, Organizations, and Committees

The standards world is a confusing tangle of organizations, committees, standards, and overlapping (and sometimes missing) content. However, it is important and codifies the results of detailed deliberation and consensus. It is critical to know what content is relevant, what standards may need to be changed, and where a standard on lighting might eventually be developed and deposited.

We surveyed the scopes of organizations, committees, individual standards, the content of the standards, and standards processes that will become relevant to lighting control standardization in later phases of this project. Only standards which speak to the details of the user interface are relevant. In this report, “standard” refers to an industry or technology standard, of the type created by the organizations discussed below. We reviewed entire organizations and particular technical committees and standards for their relevance, as well as the content of select standards and what they say for lighting control user interfaces. Full detail can be found in the main report for this project.

The International Electrotechnical Commission (IEC, iec.ch) is the body that is seen as the highest authority for issues relating to electricity. It has a very wide scope, and naturally covers issues related to the production of light from electricity. The IEC has many standards that inform the lighting UI, but none speak to it as a specific goal.

A key topic for lighting is symbols, and in the IEC this is controlled by TC 3 / SC 3C via the IEC symbol standard IEC 60417. This contains hundreds of symbols, of which many are relevant. Another committee, TC 16 maintains IEC 60073, which covers color meanings, and arrangement and “coding principles” of indicators and actuators for "man-machine interaction".

The International Organization for Standardization (ISO, iso.org) covers a wide variety of topics such as materials, equipment, products, processes, and systems. Like the IEC, it has standards that inform the lighting UI only in a general sense, and its graphical symbols committee, TC 145 / SC 3 maintains ISO 7000; this contains literally thousands of distinct symbols.

The International Commission on Illumination (CIE, cie.co.at) deals with “all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology”. It is only recently (late 2009) that the CIE created a technical committee that is relevant to this project: TC 3-49: Decision Scheme for Lighting Controls for Tertiary Lighting in Buildings. While the user interface does not seem central, it is plausible that their interest could be steered to this, or that individuals from the committee would find the topic of interest.

The Society for Automotive Engineers – International (SAE, sae.org) covers vehicle standards for various domains. SAE J2402 “specifies symbols (i.e. conventional signs) for use on controls, indicators, and tell-tales applying to passenger cars, light and heavy commercial vehicles, and buses, to ensure identification and facilitate use". It also indicates the colors of possible optical tell-tales, which inform the driver of either correct operation or malfunctioning of the related devices.

In addition to international bodies, we also surveyed relevant U.S Standards Organizations. The Illuminating Engineering Society of North America (IESNA, iesna.org) also covers Canada and Mexico, but functions like a national organization in relation to CIE. IESNA has no standards committees that clearly have the user interface in their scope. However, we do expect to find individuals within IESNA interested in the UI topic and should engage the organization. The National Electrical Manufacturers Association (nema.org) is a trade association that also has standards activities. It is the primary trade organization for the lighting (and lighting controls) industry. At present, neither organization has any standards that from their title are likely to touch on user interface issues. However, in both we expect to find interest and help, and possibly a forum for initial standards development.

Individual Standards

This section covers existing standards that inform functionality that may be used in lighting control user interfaces. We begin with symbols as they are likely the most important aspect of generic communication for lighting and similar controls.

The two most important set of symbol standards are IEC 60417 (IEC, 1998) and ISO 7000: (ISO, 1989). Common symbols such as we envision for use on lighting controls could be plausibly put into either standard (and in the end it does not matter which). IEC 80416-1 (IEC 2000) provides guidance on creating graphical symbols. Other standards specify symbols (and icons) for displays, but we do not expect display-specific symbols for lighting — we expect them to be generic to all formats.

The key indicator standard is IEC 60073 (IEC 1996). It includes specifications for color assignments, audio indications, and flashing rates. IEC 447 (IEC 1993) provides many basic principles for user interface design, including concepts (e.g. error conditions), and physical indications or actuations. There are standards that provide general guidance on principles for designing interaction scenarios with software systems, though many of the principles can also apply to hardware.

There is no question about the merit of having user interfaces accessible to those with some sort of disability; the question is what can be specified. In the power control project, extensive effort was made to identify accessibility content, but with only limited results. So, success in addressing accessibility should not be assumed. Common disabilities to consider are deafness, blindness, limited vision, limited motor ability, and special needs of the elderly and children.

Common UI content

There are several types of user interface content that span across many energy-related contexts. These need to be considered for lighting user interfaces, but not likely part of a standard for lighting specifically. Some of these are generic functionality that applies to any user interface (e.g. lock/unlock, help, scrolling, undo, etc.) and may be expressed as symbols, images, or words. Other common UI content applies to several areas of energy-related controls, and should be harmonized across them. Examples include scheduling (clocks, timers, sweep systems), and occupancy sensors (e.g. audio, infrared, ultrasonic) and indicators. Supervisory control states such as low-power or demand-reduction status may also be common across energy-related controls.

Common content is mainly found on more sophisticated controls, so only emerging in the general lighting context. Clear elements of this are quantity (to increase or decrease), scheduling, time and timers, and locking and unlocking.

The area of terminology is generally used in standards circles to include only terms used for technical purposes, not those terms used by ordinary people. As such, the topic is only marginally related to the User Interface Standard, though it is advantageous for internal and user terminology to be consistent.

Specific Interface Elements and Content

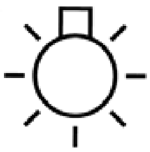
This section reviews specific content in existing standards that may be relevant to lighting control user interfaces. The goal is to present and discuss the content, not to come to conclusions. The content is organized by: symbols, (color) indicators, terms, and physical mappings. In designing interfaces and selecting elements, IEC 447 notes that users must have a workable “mental model” of the system being controlled.

Symbols

There are two basic methods for communicating diverse concepts to people: words, and symbols (colors and sounds have a more limited range and use scenarios). Words are language-specific (and sometimes more specific than that) and so have disadvantages for communication meant to be international. In addition, words often take up more space than symbols do, and are often visually more obtrusive. There is always a need for a standard translation of each symbol to a word (or short phrase), so the two are complementary, not in conflict. We can be sure that symbols will be an important part of future lighting control user interfaces. The full report for this project includes a review of many symbols, mostly from ISO and IEC standards.

The discussion below is organized by the general purpose of the symbols, as they relate to this project.

Lighting in General



A basic starting point for symbols is one (or more) that indicate to the user that lighting is involved. One of the early symbols in the IEC catalog (number 12, with its number of 5012) is for "Lamp; lighting; illumination" — — defined as "To identify switches which control light sources, e.g. room lighting, lamp of a film projector, dial illumination of a device". The core appears to be an abstracted ceiling light fixture or standard “A-lamp”, with rays of light emanating from the light source. Both of these concepts seem solid and important, and there seems nothing problematic with this symbol. It could be argued that over time, the A-lamp shape of a bulb will disappear, as we move to more solid state lighting. While this may well be true, it is likely that the convention for the symbol of a light bulb will hang on for much longer. The SAE standard renames the general lighting symbol to mean "Master lighting switch".

There is an interesting general graphic resemblance between and – the lighting and power symbols. Both have a circle interrupted at the top by a vertical rectilinear element. To all appearances, this is strictly a coincidence, but are the core symbols for energy-related user interface topics.

Many light-related symbols in the ISO standard use the convention of emanating rays for light, particularly for automobile controls.

One symbol which uses the emanating rays is "Brightness, brilliance" , and its definition notes using it for a dimmer — "To identify the brightness control, for example of a light dimmer, a television receiver, a monitor, an oscilloscope" (a related symbol is for a combined brightness and contrast control). However, this is for a particular lighting function, not the general idea of lighting. In the context of a TV, is the only control highly related to lighting (though proliferation of ambient light sensors could change this). However, in a lighting control, it may be too similar to other lighting symbols to be very useful.

Cars have distinct symbols for many types of lights: headlights (multiple types), parking lights , interior lights , and others. It is likely that we will need to have symbols for specific types of lights in buildings (e.g. emergency lighting, general lighting, and task lighting). The key characteristic should probably be the emanating rays. These examples from the SAE standard, for a Parking light, and for lighting of the instrument panel) show how sometimes symbols need to communicate two concepts and so combine them. SAE does this frequently, including for light-relate symbols, e.g. for Low-level interior illumination (night driving), which could be applied in buildings, as for a night light.

The rest of the symbol topics we present only briefly. See [Nordman, 2010] for more detail.

Basic Control

Basic control of lighting covers switching between no light and some light. For most lights today, "on" is made apparent by a switch position (assuming not a 3-way switch) or the fact that the light in question is visibly on. For electronics, power control is usually organized around the Power symbol ⏻ for a control that changes the power state, and/or is adjacent to a power indicator. The Power concept seems possibly applicable to an entire lighting control system, but not particularly to conventional control of an individual light sources. While | and C (on and off) are not commonly used on light controls today, they may be in future.

Dimming

Beyond simple binary on and off, there are dimmed states in between. There is no existing symbol clearly for this, but the closest is Variability — "To identify the control device by means of which a quantity is controlled"; there are also many variations of this symbol defined.

Characteristics

While the quantity of light (dimming) is likely the most important topic in the near term, there are other characteristics that should be addressed. One of this is color, and while today this is not commonly adjustable, it may be in future. There is a standard symbol for "Colour" which can be reproduced with red, green, and blue dots. This has been most widely seen on TVs.

There are two basic symbols for Colour temperature: one for natural light, and one for incandescent lamp. These were designed for cameras, not for light sources, and seem sufficiently close to the brightness and lighting symbols as to be confusing if used for lighting controls. There are symbols for Light and Dark but these are intended for photocopiers, not for light sources.

Non-lighting symbols

Some lighting controls also control entities other than light sources, so that symbols for those may be expected to show up on lighting controls. Common examples are exhaust fans, window shades, and switched outlets.

Indicators

Visual indicators are most familiar as a single LED with a color and stable on, stable off, and flashing states. Any indicator can inherit the generic associations from color and flashing discussed above, as well as being in a particular context from where it is, or a term or symbol near it. In many cases, an indicator is only intended to communicate on and off, with no meaning attached to the color used. This is particularly an issue as for many years, only red LEDs were widely (and cheaply) available, and still today, there are price and energy use differences between different colors that inform design decisions In addition aesthetic design concerns drive many design decisions. So, a challenge is to distinguish when color matters, and when it does not.

The correspondence between particular colors and meaning has a very long history; even in nature, animals use color to communicate within and between species. Many color associations are common in contemporary life, such as temperature (red:hot; blue:cold), traffic signal lights (red:stop; yellow:caution; green:go), and power control keys on many mobile phones (red:off; green:on). Color was also important in the power control user interface project (green:on, yellow:sleep; off:off). IEC 73 covers color associations, as well as visual associations (e.g. shape and flashing), sound (pitch and pattern), and tactile sensations.

Terms

Most terminology is defined within some professional context, to enable people to communicate with precise meaning. The International Lighting Vocabulary and Nomenclature and Definitions for Illuminating Engineering [XXXXX] contain definitions for lighting terms used in this document including fixture/luminaire, lamp, color, daylight, light source, dimmer, etc.

Physical Mappings

Physical actions of people with respect to controls manifest themselves in several ways: what they do with “actuators”, and how mental models used in metaphors, and affordances. An actuator is something that allows mechanical motion of a person to be communicated to a control. IEC 447 catalogs these as a handle, knob, push-button, push-push button, push-pull button, roller, plunger, light pen, mouse, keyboard, and touch sensitive screen. IEC 447 specifies a number of associations for common physical actions, e.g. increasing quantity is up, clockwise, to the right, and away from the user.

In interface design, metaphors comprise a set of icons, images, actions, and processes that leverage a user’s existing knowledge of how things work, to make interfaces understandable. A common example used to illustrate the concept of metaphors comes from personal computers, where the ‘desktop’, and folder icons are used to represent the operating system’s file system.

Application to a lighting standard

There is a rich vocabulary of existing interface elements in standards that are or could be relevant to lighting controls. Some elements will likely be adopted directly; some might need some adaptation or application language; and some should be rejected for use with lighting. Some new elements, particularly symbols and words, are likely needed.

Framework and Survey

This section presents the results of a survey of existing lighting controls was conducted, and a framework was developed to characterize the interface elements that they comprise. A set of representative residential and commercial lighting controls were surveyed to identify the relative prevalence of elements, and the representation of the control functions associated with those elements. Two hundred eighteen products from 44 vendors were surveyed, including those intended for both residential and commercial building environments. The survey was not intended to reflect the current stock or sales of controllers, but rather oriented to what is most useful for understanding future directions. The highest-level categories in the framework are forms, and visual tactile and audio elements.

Form

Form is a top-down assessment of the entire interface that characterizes the type of control presented to the user. Common forms we defined are switches, dimmers, scene controllers, home automation systems, and handheld remote controllers.

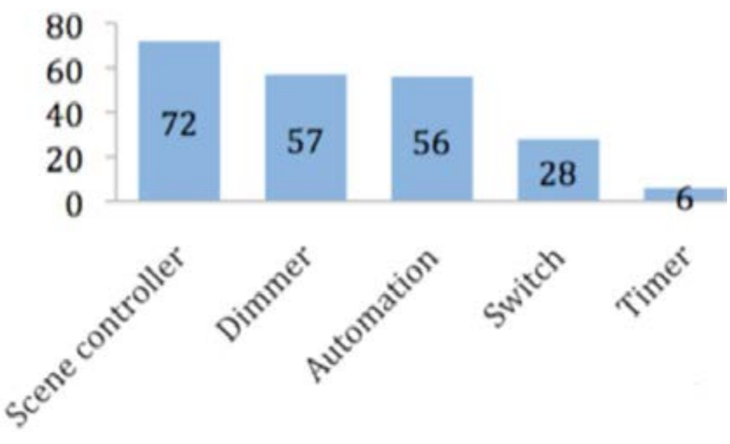


Figure 2: Relative prevalence of the form of 221 lighting controls surveyed in the study

Figure 2 shows that scene controllers, dimmers, and home automation systems comprised the most common forms in the 221 interfaces that were surveyed. This was largely driven by the selection criteria, which emphasized current trends. Thus, more traditional control options such as on/off switches and timers were less prevalent in the sample.

Elements

In addition to the overall form of control, interface characterization framework defines visual, tactile and audio elements. ‘Elements’ are "atomic" units of the interface (that cannot be subdivided), such as words, symbols, and indicator lights. Elements may be static (e.g. printed on the control), or dynamic (e.g. indicator lights that flash).

Visual Elements

Visual elements assist occupants in understanding lighting control functions before actually using the control. Visual elements commonly include words, symbols, numbers, letters, images/pictographs, and may be dynamic or static. We categorized visual elements only for mechanical interfaces, due to the multiplicity and configurability of control 'pages' offered in software-based interfaces.

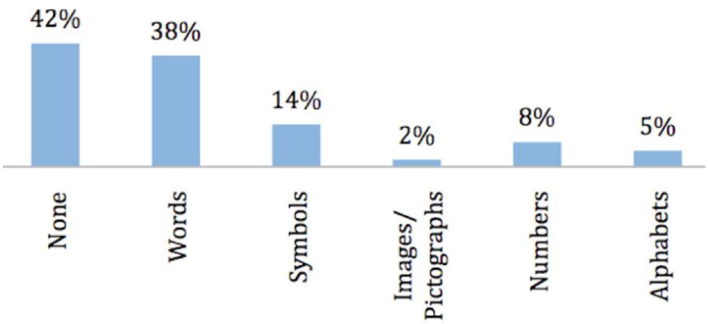


Figure 3: Relative prevalence of static visual elements on 166 mechanical interfaces surveyed.

Figure 3: Relative prevalence of static visual elements on 166 mechanical interfaces surveyed.Figure 3 shows that almost half of the mechanical interfaces did not have any visual cue. The survey findings are driven by the large number of scene controllers, which tend to be more complex, and the fact that dimmers and switches tend to have the fewest visual elements. Words were the most common visual element. The total is > 100% as some had multiple types.

Word elements were categorized into seven categories: command, location, fixture type, setting, time, and number/alphabet combination. Commands include switch on/off variations; location labels designate physical areas, such as 'kitchen'; fixture labels refer to types, such as downlights, or sconces. Some word labels identify activities, e.g. 'entertaining'; others are generic, e.g., scene 1, room A.

Symbols commonly used include power, lighting control mode, and brightness. Power control is most commonly represented by the power symbol ⏻. Some include | for on and C for "off." Lighting in general is symbolized by an incandescent light bulb shape ☼ or a luminous ball. Symbols for brightness control include arrows, + and –, wedge-shaped ramps, and slide bars. Arrows are very common on hardware keypads, and slide bars are more common on touch screens. Few interfaces actually include a symbol for the concept of brightness, but instead imply it with those such as to increase/decrease.

Dynamic visual elements that were identified included colored indicator lights for both control interfaces and their associated occupancy sensors. Digital wall-box lighting controls use colored LED lights as locator elements, or as an indicator for brightness level. For wall-box units with occupancy sensing, indicator lights show the system is working as it detects occupant presence. Blue and white lights are generally more prevalent in newly-designed interfaces.

Tactile and audio elements

Tactile and audio elements provide feedback during or after the interaction. Tactile elements include cues that can be felt by touching the surface of the interface. When an occupant touches an interface, haptic feedback felt after an action indicates that the control engaged; an example is the changed position as felt (e.g. of a rocker switch). If the lights or settings do not change, it may be an indication that the action must be performed again. Audio elements, such as a clicking sound, notify the user that interaction with the device caused a change in the system (e.g. scene setting change). In rotary dimmers, audio, and tactile feedback are commonly used to indicate light is been turned off. In step dimmers or rotary switches, audio feedback indicates a different brightness level is reached. Because people are usually trained to understand the audio feedback in lighting controllers, newer technology mimics the clicking sound when lighting level is changed.

Lighting Concepts, Mappings, and Applicable Standards

The notion of 'concepts' provides a useful system to consider families of functionality found in interfaces. For example, in an automobile, dashboard controls encompass several concepts. The ventilation concept covers fan (speed), vent outputs, recirculate - terms such as "AC", and colors to indicate hot and cold. Concepts are often separable from each other, and are commonly served by a collection of elements.

A UI element for a given concept can serve one of several roles (sometimes at the same time): Presence of capability, e.g. that a sensor is present; Labeling of an indicator, e.g. an occupancy sensor showing presence; Labeling of an actuator, e.g. a dimming control; and Name of a selector, e.g. in navigation on a touch panel to a different screen.

The same element can often be used for different purposes. For example, the word "Power" or the power symbol – ⏻ – can be used to label a switch, an indicator, or a selector for a control panel. This is similar to a single word being used as both a noun and a verb ("sleep" being an example of this). One distinction among concepts is that some are primarily static, or manual, and others are more dynamic, or automatic.

The following is an initial classification of concepts around lighting. This can be expected to evolve in later phases of the project. An initial lighting user interface standard is likely to be organized around one or more of these concepts.

Concept	Comment
Lighting in General	the overall concept of lighting, for when other controls also present
Basic switching	on/off control
Dimming	static control of light levels
Characteristics of light	e.g. color
Physical mappings	e.g. that more light is up or to the right
Scheduling / timers	time-based control of light levels
Dynamic control	e.g. from occupancy or daylight sensors
Scenes	complex settings for collections of light sources

Table 1. Basic "Concepts" in lighting user interfaces

Discussion

Results

In general, what we found confirmed rather than challenged our expectations, but we are now on much more solid ground in asserting those points. We found no existing standard focused on our topic, but no barrier to creating one.

We did not find any literature narrowly targeted on our topic, but rather it is oriented to entire interfaces in general or for other purposes. In particular, the literature does not much address individual elements. A topic that sometimes arises in user interface research (and in our standards review) is accessibility to people of various types and abilities. Particularly as our population is gaining many more elderly, the issue of accessibility should be an explicit component of future research.

The survey approach proved sound, though a future phase should include a special focus on software-based interfaces that require extra effort to obtain screen-shots of. Understanding existing controls requires analyzing them with several different approaches: overall form, individual elements, distinct concepts, and the nature of the interaction (i.e. direction of communication between device and person, and whether elements are static or dynamic).

Most basic hardware-only interfaces have no visual cues at all; while this is justified for the most simple ones, this convention becomes problematic as they gain more and more capability. The screen-based interfaces not surprisingly have a much richer palette of elements they utilize than mechanically-oriented interfaces (not surprising as their total functionality is also usually much greater). In general, words are the most common element found, which may be problematic for internationalization of controls. The most variety of implementation comes in those elements which are dynamic, such as indicator color and flashing.

In general, we found this topic very amenable to our research approach and the results were of the form we were seeking.

Content development

In terms of the content of a standard, some individual elements seem fairly solid already in terms of use on products, compatibility with existing standards, and clarity; lighting in general, , is an example of this. In other areas, particularly for symbols, it does not seem clear what to use, e.g. for occupancy sensing and daylight sensing. For concepts, the best candidates seem to be lighting in general, dimming, and dynamic controls. Both color control and scene control probably need more development and experimentation in products before initiating standardization. Scheduling and timing probably would benefit from standards now, but should consider the full range of end uses and may end up in a different standard. A focus on specific tasks may help understand how error conditions affect user interface needs.

Elements of analysis that need to be deepened or added to future work include emerging software/display interfaces, accessibility, and internationalization. A possible line of research is to evaluate overall usability of specific interfaces (as is being done for climate control), to measure how effectively people can accomplish specific tasks; whether this should be part of the next phase of work on this topic is not yet known.

We can expect increasing integration of lighting with other systems and information sharing between these systems. This will increase the need for coordination and common content. Also, since this will eventually be a global standard, further consideration of the role of language and words is required.

Process

A particularly plausible path forward would be to create a national U.S. standard, and then submit that to CIE for consideration as an international standard. An issue less clear is where to put “common content” that spans two or more energy-relevant user interface topics (e.g. both lighting and climate, as with scheduling and time); presumably this should be specified in one place rather than repeated for each end use.

The first next step that is envisioned includes creating broad recognition of the possibility and need for a user interface standard. A workshop will be critical to bring together key people from major manufacturers, relevant standards organizations, interested government/policy organizations, and the lighting research community. This would serve to help refine the concept, gain support, and improve the project plan.

This would be followed by research on UI topics particularly necessary for the first version of the standard. Then, a first draft of the standard would be prepared, and brought to the standards development process of the standards organization most suited to the topic. Throughout this there would be close coordination with manufacturers.

Bringing the content of the standard to the marketplace could be accomplished through several routes. One would be the direct influence on manufacturers as they work with us on developing its content, in initial stages and through standards organizations. Another would be through voluntary measures as through Energy Star and utility programs. Whether it is necessary or desirable to bring any of the standard content to mandatory regulations is not yet known, but certainly a possible approach. Again, the goal is to affect the entire market for lighting controls, with a commensurately large impact.

Conclusions

Lighting controls are becoming more capable, and consequently more complicated. In other domains, user interface standards have been essential for usability and safety. While no current standard speaks directly to lighting control user interfaces, many existing ones have relevant content that needs to be considered or incorporated. Many existing symbols can be incorporated or adapted for use in lighting controls, though some new ones and application guidance are likely necessary. A standard for lighting control user interfaces will also need to address indicators, terminology, physical mappings, and overall "concepts" that collect multiple interface elements in an overall set of meanings. In our survey of existing controls, we found suitable ways to categorize their overall form, and catalogued the elements we found. Visual elements were most prominent, and within that, words most commonly used, followed by symbols, images, numbers, and letters. It seems likely that symbols need to play a larger part in future interfaces. We see a clear road ahead for gaining interest and consensus around the need for a standard, and necessary further research before we can consider its precise content. Ultimately, this needs to be an international standard, much as with other successful user interface content.

Acknowledgement

Research funding was provided by the California Energy Commission, Public Interest Energy Research Program, under Contract 500-03-026, and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We thank the Dustin Davis and others at the CEC for their help. Invaluable contributions from Kosta Papamichael and Alan Meier.

References

CIE 2009. International Lighting Vocabulary, CIE Draft Standard DS 017.2/E:2009, co-published with the IEC, 2009.

IEC 1993. Man-machine interface (MMI) — Actuating principles. IEC 447, Second Edition. Geneva, Switzerland: International Electrotechnical Commission. 1993.

IEC 1996. Basic and safety principles for man-machine interface, marking and identification — Coding principles for indication devices and actuators. IEC 73. Draft, Geneva, Switzerland: International Electrotechnical Commission. 1996.

IEC 1998. Graphical symbols for use on equipment. IEC 60417. First Edition, Geneva, Switzerland: International Electrotechnical Commission. Part 1: Overview and application; Part 2: Symbol originals. 1998.

IEC 2001. Basic principals for graphical symbols for use on equipment — Part 1: Creation of symbol original. IEC 80416-1. Draft, Geneva, Switzerland: International Electrotechnical Commission. 2001.

IEC 2002c. Basic principals for graphical symbols for use on equipment — Part 3: Guidelines for the application of graphical symbols. IEC 80416-3. Geneva, Switzerland: International Electrotechnical Commission. 2002.

IEEE 2004, IEEE 1621, Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments, 2004.

IESNA 1996, Nomenclature and Definitions for Illumination Engineering, ANSI/IESNA RP-16-96.

ISO 2004. Graphical symbols for use on equipment: Index and synopsis. ISO 7000. Fourth Edition, Geneva, Switzerland: International Organization for Standardization. 2004.

Nordman, B, Granderson, J, Meier, A, Papmichael, K, Cunningham, K, Wu, K. 2010. Lighting control user interface standards. Prepared for the California Energy Commission Public Interest Energy Research program. LBNL Report.

Nordman, Bruce, The Power Control User Interface Standard — Final Report, prepared for the California Energy Commission, 2002. P500-98-032.

SAE 2010: J2402_201001 - Road Vehicles - Symbols for Controls, Indicators, and Tell-Tales, 2010.

DISCLAIMER

The role of the eco-label in the promotion of energy-efficient domestic lighting – the example of the Blue Angel in Germany

Stéphanie Zangl, Dr. Dietlinde Quack

Öko-Institut e.V.

Abstract

Household lighting has already been part of environmental policy measures for some time: the EuP implementing measure 244/2009/EC has set out clear targets with regard to energy efficiency, lighting quality and consumer information requirements for non-directional household lamps [5]. These minimum requirements are supplemented with maximum concentration values for mercury regulated under the RoHS Directive (2002/95/EC) [9]. Furthermore, most lamps on the market (except LED lamps) need to wear the energy label indicating the energy efficiency class [6]. In addition to these legal requirements, eco-labelling is an environmental policy instrument that is currently being updated and adapted to the new legislative framework [3]. This paper will present how criteria were developed for the German eco-label Blue Angel and how they relate to the minimum legal requirements and the European eco-label that is still under development.

The challenge for the development of household lighting eco-label criteria is to identify relevant environmental and in the case of lighting energy-efficient aspects of household lamps as well as to select a number of quality criteria that will give the labelled products the necessary aspects to be a good quality and at the same time environmental-friendly choice. In this respect, the Öko-Institut together with the German Environmental Protection Agency (UBA) developed criteria that have recently been finalised and published [2]. In parallel, criteria of the European ecolabel are currently being updated [3].

Background

Climate protection is one of the main challenges of this century. This has been accepted as consensus in society and each individual tries to make a contribution to this effort. But the key energy-saving opportunities are often associated with large financial or habit-related barriers, as e.g. improving the energy performance of buildings or the switch from light bulbs to energy saving lamps. Climate protection therefore requires low-threshold offers to reduce the individual carbon footprint. At his daily purchasing decision the consumer must be enabled to pick the best product in terms of climate protection and to influence the market by his conscious consumption.

Against this background the development of criteria for selected product groups with a view to allow eco-labelling of consumer-relevant products that offer a high energy saving potential has been a high priority on the environmental policy agenda. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) thus recommends in a memorandum about Product Carbon Footprint[1] the well-established Blue Angel eco-label as an appropriate label for the communication of best products within Germany. The label shall in the future mark all major product segments (except food) that are particularly energy-efficient or make a particularly large contribution to energy savings. Additionally these products meet requirements on other important environmental characteristics such as harmful substances, recyclability, complying with water conservation and low noise emissions.

A consortium of research institutions, led by the Öko-Institut, was commissioned by the ministry to develop eco-label criteria for altogether 100 climate-related products – among them household lamps including compact fluorescent lamps (CFLs) and LED lamps. This paper will introduce the criteria development process for this product group as well as the criteria themselves. As the environmental product policy instrument of eco-labelling for the product group lamps has not only been an issue on national level but also on EU level, this paper will also compare the German Blue Angel criteria [2]

---

1 http://www.bmu.de/english/ecological_industrial_policy/downloads/doc/45365.php

with the EU's eco-labelling criteria which are not yet officially published but which have been voted in the EU's eco-labelling board [3]. Furthermore, as eco-labelling is a voluntary instrument which is based on legally binding minimum requirements, the eco-label criteria will be compared to existing EU lamp regulations issued in the context of the EuP Directive on non-directional household lamps [5] as well as on recommendations for directional household lamps [7].

Criteria development process

In Germany, the criteria for the Blue Angel are developed in a stakeholder process that involves as much academia as industry, consumer and environmental NGO representatives and also testing institutions. Usually this process is led by the German Federal Environmental Agency (UBA) which is supported by a consultant. In the case of lamps, Öko-Institut was in charge of the scientific analysis of the product group which forms the basis of criteria development.

This analysis was done in close cooperation with UBA as the energy efficiency of lamps has been investigated there for a long time already and a large amount of data was available that was used for the development of some of the criteria. In addition, Öko-Institut undertook research in the field of lamp quality and performance parameters as they also form an integral part of the eco-label (high quality products that are environmentally friendly).

As a preparation of criteria development, a scientific study was undertaken that analysed the following issues [1]:

1. Description of the different lighting technologies for household lamps (GLS, CFL and LED).
2. Market analysis (penetration in households, prices, technological development on the market)
3. Energy efficiency (assessment of the use of mercury, LCA results on the comparison of LED lamps and CFLs as well as the EU's energy efficiency label).
4. Existing legal requirements at EU level (EuP and RoHS).
5. Existing eco-labels (EU, energy star, UK's EST)
6. Quality aspects (technical parameters, standards, testing).
7. Life cycle assessment (orientating LCA, life cycle costing)

Based on the existing data and findings from UBA and Öko-Institut a first screening meeting was held with stakeholders. On that basis the above mentioned scientific study was carried out. Derived from the findings of this scientific study, a first set of criteria was developed which was then presented to stakeholders during a first meeting. After that, on the basis of results from discussions, further analysis was undertaken and a second criteria proposal was presented to stakeholders at a further meeting. The finalization of the criteria and the discussions were quite complex and lengthy due to the fact that the criteria should cover both energy-efficient household lamp technologies (CFL and LED). Especially lifetime requirements were an issue since LED household lamps were quite new on the market and standards and testing were not yet fully developed making requirements more difficult to verify. Further details will be given in the next section describing the individual criteria.

In between the two stakeholder meetings, individual criteria were discussed bilaterally with specific experts. After the second stakeholder meeting the criteria were finalized as well as all the necessary verification documentation including an Excel sheet that needs to be filled in by applicants. All documents have now officially been published on the Blue Angel's website and applicants can use them to apply for the eco-label[2]. Unfortunately until now, no manufacturer has applied.

[2] http://www.blauer-engel.de/en/products_brands/vergabegrundlage.php?id=207

Criteria

In this section the criteria developed for the Blue Angel for household lamps will be presented and discussed in detail.

Climate protection, reduction of energy consumption as well as avoidance of pollutants and waste are major goals of environmental protection. Lighting accounts for 10 percent of all electricity used in Germany (in comparison: EU 16 % and worldwide 19 %). German households use about 8 percent of the electricity for lighting. Thus, electricity consumption for lighting of a statistical average German household adds up to almost 300 kWh per year. Due to the importance of lighting for the above-mentioned environmental goals the aim of a Blue Angel eco-label for lamps is to support increased market penetration of products providing the following properties [2]:

1. good photometric properties such as
   - good colour rendering,
   - low deviation of colour temperature and colour,
   - long service life time,
   - high switching endurance,
   - low premature failure rate,
   - short warm-up time;
2. high energy efficiency;
3. low mercury content;
4. low UV radiation and electromagnetic field radiation;
5. transparent consumer information.

The goal was to find parameters with which labeled lamps could be marked as lamps that offer benefits to climate protection and the environment in general as well as a high level of lighting quality.

Energy efficiency

Within the eco-label's role to promote environmentally friendly products, energy efficiency plays an important part since as many studies have shown the main environmental impact is related to the energy consumption in the use phase [1].

Energy efficiency requirements already existed since an EU eco-label was in force [4] as well as minimum legal requirements for non-directional lamps [5]. Furthermore, the EU energy efficiency label exists [6], however, not applicable for LEDs. The latter made it difficult to refer an energy efficiency criterion to existing energy efficiency classes for lamps.

However, the EU energy efficiency label uses a formula to categorise a lamp's energy efficiency into class A that could be used as a criterion for an eco-label: $W \leq 0{,}24\ \sqrt{\Phi} + 0{,}0103\ \Phi$ (where W is the lamp's power consumption in W and Φ is the lamp's luminous flux in lumen). A requirement for the eco-label could thus be $W \leq (0{,}24\ \sqrt{\Phi} + 0{,}0103\ \Phi) * 0{,}9$ making eco-labelled lamps 10 % more energy efficient than lamps with the label A [1]. This approach has been chosen by the EU eco-label and also applies to LED lamps [3].

Nevertheless, for the Blue Angel a different approach was chosen. UBA had on the basis of manufacturer data developed a formula that takes the influence of the colour rendering index into account (the higher the colour rendering is, the lower is the efficiency): EGN_{max}[3] = 10,697 + 0,291 ×

[3] EGN stand for an index of the electrical energy.

R_a [1]. The energy efficiency criterion is considered met when the mean power consumption resulting from the following formula based on the mean luminous flux is lower than the EGN value: $P = 0{,}01029 \times (0{,}88 \times \sqrt{\Phi} + 0{,}049 \times \Phi)$[4] [2].

During discussion with stakeholders in the context of the criteria development process it appeared that this criterion was ambitious enough and could at the same time be met by certain manufacturers and also be proven by test results. Hence the criterion is verifiable and was thus accepted by all participating stakeholders.

Power factor

The power factor gives an indication on how much of the apparent power is transformed into active power and is thus important for the load on the electrical grid which is induced through the use of a lamp which is in this case considered as a consumer load [1]. This is why in the minimum legal requirements for non-directional lamps (except for LED lamps) a power factor has been set [5]:

Requirements for the electrical power factor of non-directional lamps in 244/2009/EC

Level 1	Level 2
≥ 0,50 when P < 25 W ≥ 0,90 when P ≥ 25 W	≥ 0,55 when P < 25 W ≥ 0,90 when P ≥ 25 W

(Source: EU Directive 244/2009/EC)

As these minimum legal requirements are only valid for non-directional lamps except for LED lamps, it was decided to include power factor requirements for LED lamps into the criteria for the Blue Angel. In agreement with stakeholders the following values were set:

Requirements for the electrical power factor of LED lamps in RAL-UZ 151 [2]

Criterion	Requirement LED-Lamps
Active power < 25 watts	Power factor ≥ 0.75
Active power ≥ 25 watts	Power factor ≥ 0.90

(Source: RAL-UZ 151)

Lamp quality

For a lamp’s quality photometric parameters are of importance. This is why an eco-label should include requirements on colour rendering and colour temperature. Furthermore, the quality also depends on lifetime, switching cycles and warm-up time [1].

Colour rendering

Minimum legal requirements in EU Directive 244/2009/EC already set the quite ambitious level of a colour rendering index equal or higher than 80 [5]. At least for household lamps the requirements are not as high as in professional applications so that a colour rendering index of 80 seems to be ambitious enough. This has been confirmed by lighting experts. However, in order to ensure constant quality during the lamp’s operational lifetime, it was decided to request a colour rendering index of equal or higher than 80 over the whole lamp operation duration [2].

The new EU eco-label criteria set the requirement at a colour rendering index of 85 [3]. This might be due to the fact that the lamps covered by the criteria include some professional applications (e.g. double-ended lamps).

Colour temperature

With respect to colour temperature, no minimum legal requirements exist. However, some standards deal with this parameter and especially the LED lamp related standard IEC 62612 refers to it extensively as this aspect is of particular relevance for the latter [1]. Three parameters have been

[4] This formula has been developed on the basis of the one used for the EU’s energy label classification.

identified as relevant together with lighting experts: chromaticity coordinates, colour homogeneity and colour preservation.

In this respect the EU eco-label differs in its requirements since it has set that the light source shall have a Correlated Colour Temperature (CCT) spread within a 3-step MacAdam ellipse or better [3]. This is on the one hand less detailed and ambitious than the Blue Angel criteria described below, but on the other hand verification and testing associated with this parameter is less demanding thus lowering cost and efforts for applicants and possibly enhancing their incentive to apply for the label.

1. Chromaticity Coordinates

   The chromaticitiy of a lamp should not differ too much from the manufacturer-specified chromaticity coordinates of the colour temperature (advertising, packaging, etc.) in order to allow the consumer to get a reliable colour temperature whis is alike for any lamp he buys. That is why the colour distance between the chromaticity of a sample and the chromaticity of the specified colour temperature in 19 of the 20 test samples shall not be greater than 0.007 units on the CIE 1976 u'v' chromaticity diagram [2].

2. Colour Homogeneity

   The same rationale applies for this criterion: consumers need to rely on colour temperature of lamps independently of the batch the lamp comes from. Hence, the chromaticities of lamps of identical type should not differ too much from each other. That is why the colour distance between the chromaticity of one test sample and the chromaticity of any other test sample in 19 of the 20 test samples must not be greater than 0.006 units on the CIE 1976 u'v' chromaticity diagram [2].

3. Colour Preservation

   In addition, the chromaticity of a lamp should not change too much over the lamp's lifetime. That is why the colour distance between the chromaticity of a test sample and the chromaticity of the respective same test sample in 4 test samples must not be greater than 0.007 units on the CIE 1976 u'v' chromaticity diagram. The variation shall be individually determined for each test sample [2].

Durability of the lamp

The question how long a lamp will work at a certain level of quality is also of great importance for consumer satisfaction and hence the successful penetration of energy efficient lamps on the market. Therefore within the aim of an eco-label, setting requirements for parameters such as lamp lifetime, number of switching cycles and premature failure rate is of importance [1]. In any case minimum legal requirements exist for these parameters which can be used as a basis to define slightly higher requirements for the voluntary policy tool of eco-labelling.

On the side of legal requirements currently for non-directional household lamps only failure rates at 200 h and at 6.000 h have been set as well as requirements for lumen maintenance and switching cycles [5]. No legal requirements exist for household LED lamps. Only recommendations have been issued for the same parameters as for other household lamps [7].

An overview on both is given in the tables below:

Requirements for lamp durability of CFL according to 244/2009/EC [5]

Criterion	Tier 1[5]	Tier 5[6]
Lamp survival factor at 6 000 h	≥ 0,50	≥ 0,70
Lamp luminance maintenance factor	At 2 000 h: ≥ 85 % (≥ 80 % for lamps with second lamp envelope)	At 2 000 h: ≥ 88 % (≥ 83 % for lamps with second lamp envelope) At 6 000 h: ≥ 70 %
Number of switching cycles	≥ half the lamp lifetime expressed in hours ≥ 10 000 if lamp starting time > 0,3 s	≥ lamp lifetime expressed in hours ≥ 30 000 if lamp starting time > 0,3 s
Start-up time	< 2,0 s	< 1,5 s if P < 10 W < 1,0 s if P ≥ 10 W
Warm-up time until 60 % Φ is reached	< 60 s or < 120 s for lamps containing mercury in amalgam form	< 40 s or < 100 s for lamps containing mercury in amalgam form
Premature failure rate	≤ 2,0 % at 200 h	≤ 2,0 % at 400 h

Requirements for lamp durability of LED according to [7]

Performance parameter	Tier 1	Tier 2	Tier 3	Benchmark
Minimum rated lamp lifetime for L70F50	≥10000 h	≥10000 h	≥10000 h	≥30000 h
Number of switching cycles (IEC 62612 Ed1)	>5000 (30 sec on/off)	>10000 (30 sec on/off)	>20000 (30 sec on/off)	>100000 (30 sec on/off)
Premature failure rate for L85F05	≥100h	≥100h	≥200h	≥200h

The EU ecolabel sets the following requirements in the current version of the updated criteria [3]:

EU eco-label requirements for lamp durability [3]

Criterion	Single ended	Double ended
Life time (hours)	15,000	20,000
Lumen Maintenance	80 % at 9,000 hours	90 % at 16,000 hours

Against this background the question arises how criteria can be set for an ambitious national eco-label. The criteria would need to take the technological differences between CFLs and LED lamps into account and would also need to be verifiable. The discussion with stakeholders has led to the following criteria [2]:

---

5 1 September 2009

6 1 September 2013

Requirements for lamp durability

Criterion	Requirement
Service life time[7]	≥ 6,000 hours
Switching endurance[8]	≥ 20,000 switching cycles
Premature failure rate[9]	≤ 2 %

(Source: RAL-UZ 151)

With regard to lamp lifetime it was chosen to set the requirement at a maximum lumen depreciation of 15 % which is slightly more ambitious than the legal minimum requirement which sets a lumen depreciation of a maximum of 30 % after 6.000 h for the fifth tier. The EU eco-label on the contrary has chosen to set an absolute lifetime requirement at 15.000 h and a maximum lumen depreciation of 20 % at 9.000 hours.

Before having reached an agreement on this criterion, stakeholders had discussed a few issues:

1. Setting of lifetime requirements at a failure rate of 50 %: mostly consumer organizations argued that if a lamp lifetime statement was printed on the lamp package referring to a failure rate of 50 % this would mislead consumers as only half of the tested lamps would need to fulfil this requirement and that hence the consumer could not be sure whether the actually bought lamp would last as long as indicated. However, other stakeholders counter-argued that existing test standards refer to a failure rate of 50 % and that these standards are already referred to in other environmental policy measures. Therefore, setting requirements at a different failure rate would lead to additional testing requirements and would not be comparable with other figures.

2. Setting of relatively low lifetime hours as a requirement: as much for CFLs as for LED lamps a lifetime of 6.000 h is relatively low compared to what is stated on packages (around 15.000 h for CFLs and up to 50.000 h for LEDs). However, measurement verification of such long lifetimes itself requires quite some time and is not practicable with a view to support an application for an eco-label. Also, it was decided that the important quality aspect of a lamp is that it will keep a certain amount of luminous flux over a comparably long period of time. It was thus chosen to rather set a high lamp luminance maintenance factor (85 %) that should be guaranteed for a minimum of 6.000 h. Assuming an average operational time of a lamp of 3 hours a day, the lamp would still be in good quality operation for over 5 years.

As to switching cycles, the following table shows different definitions and requirements which were used as the basis for criteria setting within the Blue Angel:

[7] Service life time means the time that elapses during a long switching cycle (165 min ON and 15 min OFF) from the end of the burn-in time until the lamp lumen maintenance factor falls below 85 % and/or the lamp survival factor falls below 50 %.

[8] Switching endurance means the number of short switching cycles (0.5 min. ON / 4.5 min OFF) at which lamps fall to a lamp survival factor of 50 %.

[9] The premature failure rate refers to the entire production quantity. The value of ≤ 2 % shall be met by all lamps of a production in accordance with statistical calculation methods. With regard to the sample size of 20 lamps 2 % would result in only 0.4 lamps. That is why the following requirement has been established: the failure rate shall not exceed 1 lamp.

Overview on different switching cycles testing requirements [1]

Source	Long	Short	Comment
EN 60969	Minimum 10 min ON, 10 – 15 min OFF; 8 x a day		Only appears in explanatory note to standard; no switching cycle is set with regard to lifetime measurement.
244/2009/EC	Refers to EN 60969	1 min ON, 3 min OFF	Long cycle for lifetime, LSF and LLMF; short cycle for switching endurance
EU-Ecolabel	-	0,5 min ON, 4,5 min OFF	Short cycle for switching endurance; no requirement set for switching cycle with regard to lifetime measurements
Consumer testing (Stiftung Warentest)	2 h 45 min ON, 15 min OFF; 8 x a day	0,5 min ON, 4,5 min OFF	Long cycle for lifetime; short cycle for switching endurance
Testing organisation (TÜV)	10 min ON, 10 min OFF; 4 x a day		
European CFL Quality Charter	5 min ON, 10 min OFF		
IEC 62612	-	0,5 min ON, 0,5 min OFF	Short cycle for supply voltage-switching test; has to be repeated for a certain amount of cycles corresponding to half of the stated lifetime.

For the Blue Angel it was chosen to set the requirement for switching cycle endurance at 20.000 which corresponds to the currently valid eco-label criterion and lies between the minimum legal requirements of tier 1 and tier 5 for CFLs. LED lamps have less an issue with switching cycles from a technological point of view and should thus at least meet the same requirements as CFLs. The requirement of 20.000 cycles corresponds to the proposed minimum legal requirements of tier 3[10]. The currently updated EU eco-label criteria set 60.000 switching cycles which is however considered as not practicable for testing and measurement verification procedures.

The premature failure rate of a maximum of 2 % after 400 h corresponds to the minimum legal requirements of tier 5 for CFLs and is a lot stricter than the proposed requirements for LED lamps. However, as premature failure is rather an issue for LED lamps it was decided that they should also meet this requirement. This criterion is not included in the EU eco-label criteria.

Warm-up time

The table below indicates the criteria for the warm-up time until a lamp reaches 80 % of the initial luminous flux. This gives an indication on how long a consumer has to wait until the full brightness or at least a sufficiently high brightness can be reached.

Requirements for lamp warm-up time [2]

Criterion	CFLs with amalgam	Other lamps within scope
Requirement for the warm-up time measured on a burnt-in lamp until reaching 80 percent of the initial luminous flux	≤ 60 s	≤ 30 s

(Source: RAL-UZ 151)

According to data from the consumer testing organisation „Stiftung Warentest“ the agreed requirements ensure that lamps with an outer bulb and lamps with amalgam need to meet ambitious criteria but at the same time are given a small bonus compared to other lamps [1]. The above mentioned values are furthermore stricter than those mentioned in tier 5 of the minimum legal requirements. The EU eco-label does not mention this criterion.

---

[10] 1 September 2011

Mercury content

CFLs contain mercury which is considered a hazardous substance. Usually the amount of mercury in CFLs for use in households is around 2 mg [1]. It is a goal of environmental policy to reduce the amount of hazardous substances in products. Hence, eco-labelled products should have the minimum amount of mercury possible. The mercury content in lamps is regulated as minimum legal requirement under the EU's RoHS Directive. Currently, for CFLs below 30 W, a maximum amount of 5 mg is allowed. Starting 1 January 2012, 3,5 mg will be the maximum amount of mercury allowed [9].

The current draft for the new EU eco-label criteria sets a limit at a maximum of 1,5 mg of mercury for CFLs [3]. Within the discussions around the criteria for the Blue Angel, it was questioned whether an absolute amount was justified or whether the allowed amount of mercury should be determined in relation with parameters like the luminous flux and the lifetime of the lamp. Since UBA had already developed a formula on the basis of manufacturer data taking those parameters into account and stakeholders agreed that it sets ambitious requirements, it was chosen to set the following requirement [2]:

$Hg \leq 0.6 + 0.03 \times \sqrt{\Phi} + 0.00008 \times LD$ where Φ is the luminous flux and LD the lamp's lifetime.

UV radiation and Electromagnetic fields

For some lamps UV radiation can be an issue as some persons might be sensitive to it or certain surfaces might be affected. In that sense, it has been decided to set a criterion in accordance with findings from the German Federal Agancy for Radiation (BfS) [1]:

Lamps to be eco-labelled must not exceed the following values at a distance of 20 cm from the light center (as specified in DIN EN 62471) [2]:

- actinic UV radiation (250 nm to 400 nm) – Es = 0.01 mW/m²
- UVA (315 nm to 400 nm) – EUVA = 100 mW/m², based on 1,000 lux.

For a reduction by blue light hazard lamps shall additionally be classified in risk group 0 („exempt group“), as defined in DIN EN 62471.

Regulation 244/2009/EC also sets minimum requirements but these cannot be compared as they are set in a different metric: UVA + UVB radiation ≤ 2,0 mW/klm. Experts from BfS nevertheless stated that the above mentioned criterion was more ambitious then these minimum requirements.

Next to UV radiation, BfS also analysed the question of electromagnetic fields and came to the conclusion that for precautionary reasons a criterion should be set as follows [2]:

Lamps to be eco-labelled may emit electric fields at a distance of 30 cm only to the extent that the condition of F ≤ 0.3 % is met. F is the factor defined in equation E.2.4 of the assessment method to be applied for compliance verification[11].

No legal minimum requirements exist in this respect. The EU eco-label does not refer to any of the two criteria.

Consumer information

In view of ensuring a good market penetration of energy-efficient lamps, consumer information is a key aspect. They need to be enabled to make a well-informed purchasing choice. Eco-labelled products should give consumers information on the amount on energy saved, the equivalence to GLS for lamps intended to be used as retrofits concerning wattage, colour temperature and lifetime.

[11] The applicant shall establish compliance with this requirement by measurement according to DIN IEC 62493 (Assessment of lighting equipment related to human exposure to electromagnetic fields – product family standard (IEC 34/116/CD:2008)) for a randomly selected lamp and submit a corresponding test protocol. The measured value shall fall short of the required value by 4 dB. If the first measurement does not meet this criterion a second measurement shall be made which establishes compliance with this requirement.

Furthermore, the above-mentioned environmental and quality parameters should be made transparent [1]. Regulation 244/2009/EC already includes ambitious requirements with regard to consumer information on lamp packages and the internet.

In so far, it was decided to include as a criterion for the Blue Angel that the minimum legal requirements should already be fulfilled prior to tier 2[12] (point of time at which the requirements have to be fulfilled at EU level). Furthermore, it was requested that information on the proper waste management should be included, as mercury-containing CFLs should be kept out of municipal waste management I order to avoid contamination.

Conclusions and outlook

Concluding on the above presented criteria developed for the German national eco-label the Blue Angel for household lamps against the background of existing and draft new criteria for the EU ecolabel as well as existing minimum legal requirements for non-directional household lamps and existing proposals for directional household lamps, the following can be stated:

1. The Blue Angel criteria are mostly more strict than the EU eco-label criteria. This also brings along a higher complexity of some criteria leading to higher needed efforts for applications and verification testing.

2. The Blue Angel criteria are not always comparable with the EU eco-label criteria and the EU's minimum legal requirements set in Regulation 244/2009/EC making it more difficult to streamline application procedures and to compare the levels of ambition.

3. The EU eco-label criteria include criteria on hazardous substances and mixtures, certain substances of very high concern as developed under REACH, plastic parts and packaging which are not included in the Blue Angel criteria.

4. Directional household lamps are not yet regulated at EU level. The criteria for the Blue Angel as well as the criteria for the new EU eco-label include LED lamps in their scope. In parallel, an initiative has been set up by the EU Commission's JRC on a European LED Quality Charter [8]. Hence, voluntary schemes exist that allow a labeling and / or enhancement of LED lamps put onto the European market. The successful penetration nevertheless depends on the initiative of manufacturers to use these environmental policy instruments. At the moment consumers have no possibility to make an informed choice when buying an LED lamp.

5. For CFLs minimum legal requirements exist. However, it is difficult for consumers to make an informed choice if they would want to buy a high quality and particularly energy-saving lamp. It is now up to manufacturers to choose the use of eco-labels in order to identify the top products on the market.

In view of accelerating the market penetration of particularly energy-efficient and at the same high quality lamps, the use of eco-labels would give consumers the opportunity to make "green" choices with which they are satisfied as well from a performance aspect.

[12] 1 September 2010

References

[1] Zangl, S. *PROSA Lampen in Privathaushalten, Entwicklung der Vergabekriterien für ein klimaschutzbezogenes Umweltzeichen*, Öko-Institut, Freiburg, 4 August 2010

[2] RAL gGmbH. *Basic Criteria for Award of the Environmental Label, Lamps, RAL-UZ 151*, July 2010, http://www.blauer-engel.de/en/products_brands/vergabegrundlage.php?id=207

[3] European Commission. Draft Commission Decision establishing the ecological criteria for the award of the EU Ecolabel for light sources, version of 21 October 2010

[4] European Commission. Commission Decision 2002/747/EC of 9 September 2002 establishing revised ecological criteria for the award of the Community eco-label to light bulbs and amending Decision 1999/568/EC.

[5] European Commission. Commission Regulation 244/2009/EC of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps.

[6] European Commission. Commission Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps, Official Journal L71, 10.03.1998, pp. 01-08. Can be downloaded at: http://europa.eu.int/eur-lex/

[7] Vito. *Lot 19: Domestic lighting – Part 2, Directional lamps and household luminaires, Interim Task Report, Task 8: scenario- policy- impact- and sensitivity analysis*, August 2009.

[8] European Commission. European LED quality charter, 8 December 2010.

[9] European Commission. Commission Decision 2010/571/EU of 24 September 2010 amending, for the purposes of adapting to scientific and technical progress, the Annex to Directive 2002/95/EC of the European Parliament and of the Council as regards exemptions for applications containing lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers.

LED LIGHTING INSTALLATIONS IN HOUSEHOLDS IN BRAZIL, AS A PROPOSED TO SAVE ENERGY AND PROTECT ENVIRONMENT: PRACTICAL RESULTS.

MALDONADO A. O. A., SILVEIRA M. C. F., CARNEIRO J. L., SILVEIRA J. L.

Laboratório de Eficiência Energética em Sistema de Iluminação Pública - LESIP, Department of Electrical Engineering, São Paulo State University - UNESP, Guaratinguetá – São Paulo – Brazil

Abstract

The necessity to conserve energy and preserve the environment, encourages the deployment and use of more efficient technologies and environmentally friendly in all sectors of energy consumption. Lighting installations in households represent about 5% of total energy produced in Brazil. Reduce this consumption is important to reduce the necessity of investments for new generation in Brazil, where over 80% of generation comes from hydroelectric power, reduces the negative impacts on the environment arising from the creation of large water reservoirs. This paper presents the energy benefits, lighting and power quality, resulting from the use of lighting systems using LED technology, when replacing traditional systems consist of fluorescent tubes and compact fluorescent lamps (CFL), whatever the primary source of electricity, water, fuel oil, gas, etc.. It also presents the many, direct and indirect environmental benefits of replacing the fluorescent lamp discharge, which uses heavy metals and contributes to the emission of greenhouse gases, for LED lamps. Is also shown an analysis of the heat radiation of different types of technology compared in this study, discharge lamps and LED lamps to determine the positive impact of lighting in design of air conditioning in homes. The results obtained by testing experimental laboratory clearly demonstrate these benefits and confirms the technical and economic feasibility of this proposal.

1. Introduction

Lighting in household represents a considerable share of the electricity consumption in the residential sector in the European Union and Candidate Countries and the sector has been reported to consume 86 TWh per year in the EU-15 in year 1995 in the DELight Study [Environmental Change Unit]. The DELight study predicted an increase of residential lighting consumption to 97 TWh by 2010. More recently the European Climate Change Programme (EECP) [ECCP] and the 2004 JRC Status Report [JRC] calculated the following lighting consumption in the EU-15: 85 TWh growing to 94 TWh by 2010, without additional and new policies and programme introduced. Waide [Waide] calculated 79 TWh in 2005 for the OECD Europe [Ref. 01].

In the same way, according to plan for expansion of energy produced by the ministry of mines and energy in 2019, Brazil will consume 415,865 GWh of energy, and 105,538 GWh will be consumed by the residential sector. It is known that about 20% of this energy is consumed by residential lighting systems, representing an installed capacity of 2.4 GW, equivalent to the power supplied by hydroelectric plant Paulo Afonso IV, installed in the state of Bahia in Brazil[02]. A plant of this size emits daily 5,710 kg of CO_2 and 292 kg of CH_4, totaling about 1.7 ton of carbon emitted into the atmosphere every day. Cut some of this consumption is important to save energy and reduce environmental impacts.

This article demonstrates, based on comparatives analysis in the laboratory, the benefits of using the solid state lighting SSL, or LED technology in residential lighting, replacing traditional technologies currently used, based on tubular fluorescent lamps, and even compact fluorescent lamps, CFLs.

2. Analysis of energy and illuminance performance.

The energy and illuminance benefits from the use of LED lamps in interior lighting systems can be demonstrated experimentally, not only in terms of power consumption and lighting features, but also about the presence of harmonic components that compromise the quality of electric energy distribution power system.

2.1. Experimental setup. and results.

In this work lab tests were performed using the following types of lamps: 34 W LED tubular lamps, compared with 40 W tubular fluorescent lamps. Were also compared 15 W and 10 W LED E-27 base lamps, with 15 W Compact Fluorescent Lamp, CFL.

The tests were conducted inside a dark room designed for this purpose with the height usually found in homes and offices and showed in figure 01. The internal walls painted black and with dimensions of 3 meters height, 3 meters long and 2 meters wide.

The mainly measurement instruments used are, a programmable power source from Pacific model: Smart Source 345-AMX, Fluke Power Quality 435, 80i-110s Fluke Current Probe AC/DC and Chroma-Meter Minolta CL-200

Figure 01: Dark room used in tests

2.2. Experimental results.

Table 01 presents results of electrical and optical measures of lamp with E-27 base and also shows that for same operating conditions, room dimensions, and height of the work plan, the LED lamp [15W] produces 3.6 more light on the work plan that the compact fluorescent lamp and LED lamp [10W] produces about 3 times more.

Table 01: Comparison between lamps with E-27 base

	Compact Fluorescent Lamp [15W]	LED Lamp [15W]	LED Lamp [10W]
Power	15 W	15 W	10 W
THD_I	111,4%	13,6%	17,0%
Illuminance	12 lux	43,2 lux	36,5 lux
Color Temperature	5403 K	5686 K	5549 K
Luminous Efficacy*	0,8	2,88	3,65

*Illuminance/Power (lux/W)

The table 02 presents the results of comparison between conventional tubular lamps and LED tubular lamps.

Table 02: Comparison between tubular lamps.

	Fluorescent Tubular Lamp [2x36W]	LED Tubular Lamp [2x17W]
Power	65 W	34 W
THD_I	11,0%	18,9%
Illuminance	148,3 lux	291,4 lux
Color Temperature	6560	6257
Luminous Efficacy*	2,28	8,57

*Illuminance/Power (lux/W)

From tables 01 and 02, it appears that the use of tubular LED lamps brings an energy savings of 45%. The energy saved for lamps E-27base is 33%.

The total energy conserved is shown at the end of this work.

The measured illuminance levels showed in figure 02, are referent over a work plane 0,80 meters above the ground .

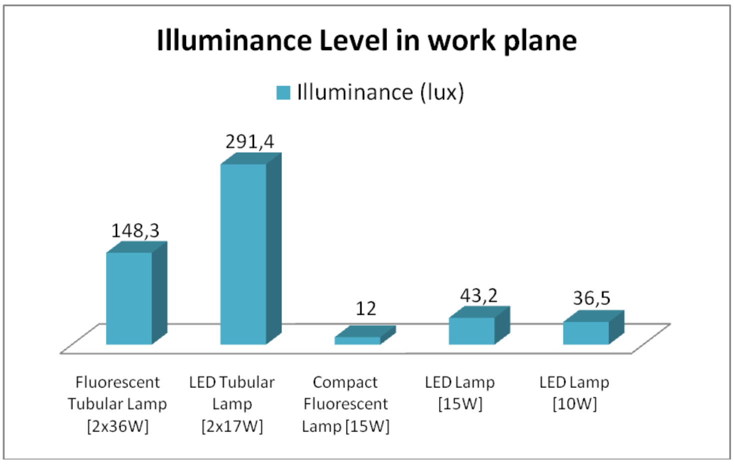


Figure 02: Illuminance level in work plane

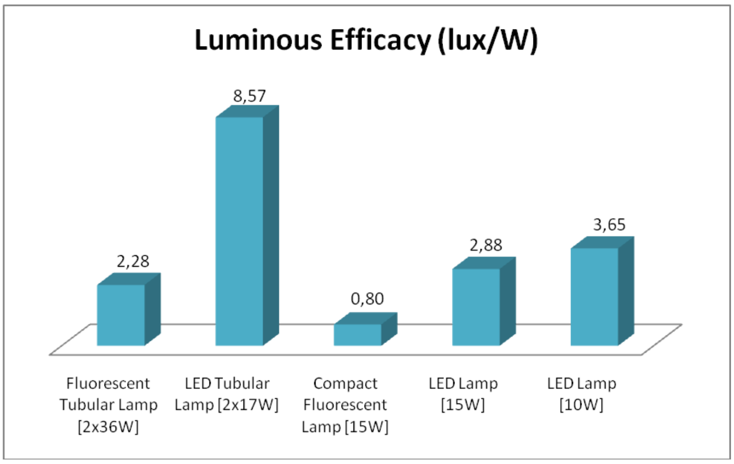


Figure 03: Luminous Efficacy

From figure 03, the efficacy in lux/watt for tubular LED lamps increases 3.76 times. For the CFL, this ratio is 3.60 to 15 W LED, and 4.56 to 10 W LED.

Total energetic results.

The growing economic and social development of the country will result in a increase in the number of residences, estimated from 61 million homes in 2010 to 74 million by 2014, according to the Empresa de Pesquisa Energetica – EPE. [Ref. 02]

Increased demand means increased investment in new generation. Energy conservation in this new facility represents a reduction of these investments and less aggression to the environment.

The purpose of this study is to encourage the substitution of traditional discharge lamps for solid-state lamps in residential installations on the basis of energy and environmental benefits.

To calculate these benefits will be considered the following scenario for residential installations.

Considering from 2010 until 2014 an increase in the number of residences of 13 million homes and considering in this scenario a common house with 2 bedrooms, 1 bathroom, a kitchen and a living room with the use at least three LED lamps for a period of 4 hours day (19:00 to 23:00), the saving electric energy will can be calculated for next way:

Energy savings resulting from replacement at less 3 x 15W CFL lamps, for LED E-27 base lamps by residence result in:

For CFL: 3 x 15W lamps = 45 W. Total consumption of 3,416.4 GWh in 4 years

For LED technology:

Case A. Use of 10W LED E-27 base lamp. 3 x 10W lamps = 30 W. Total consumption of 2,277.6 GWh in 4 years

Saved energy: 1,138.8 GWh in 4years

Case B. Use of 15W LED E-27 base lamp. Despite being the same consumption in GWh, benefits based on the quality of electric energy , lighting levels and mainly due to the environmental benefits shown ahead, recommend the use of LEDs.

For tubular fluorescent lamps.

Energy savings from replacement at less 2 x 36W fluorescent lamps, for LED tubular lamp by residence result in:

For fluorescent tubular, the consumption is: 5,466.2 GWh in 4 years

For LED tubular, the consumption is: 2,581.2 GWh in 4 years

Saved energy: 2,884.9 GWh in 4 years

3. Environmental Benefits

3.1. Mercury contamination

Mercury is a toxic metal that evaporates into the environment under normal temperature. At the end of its useful life lamps are often destined in dumps, landfills and other areas contaminating the soil and water courses causing damage to the environment and life.

The amount of mercury in a fluorescent lamp can vary according to lamp type, manufacturer and year of manufacture. This quantity is declining over the years. According to the National Electrical Manufacturers Association (NEMA), the amount of mercury in fluorescent lamps, between 1995 and 2000 was reduced by about 40% (Fox et al., 2003).

Currently, the average amount of mercury in a fluorescent lamp 40 W, according to U.S. EPA (United States Environmental Protection Agency) is around 21 mg. There is controversy regarding the amount of mercury in them. Data provided by NEMA indicate that 0.2%, or 0.042 mg are in the form of elemental mercury in the vapor state. The other 99.8% (20.958 mg) are in the form of Hg_2 + adsorbed on the phosphor coating and glass (Fox, 2001).

The complexity of the quantification of mercury species can be explained by possible interactions of mercury resulting in the formation of new species. The decontamination cost for lamp containing mercury per unit ranges around US$ 0.70 without considering the transportation costs. [Ref. 03].

In this scenario, considering that each tubular fluorescent lamp has about 21 mg of mercury, the replacement of fluorescent tubular for tubular LED, represent avoid the disposal of 546 tons of mercury into the environment in these four years.

3.2. Heat emitted for lamps and conditioning air

The conversion of electrical energy into light generates heat. This heat is dissipated by radiation to the surrounding surfaces by driving through the adjacent materials, and by convection into the air.

Incandescent lamps convert only 10% of its electrical power into light, and 90% turns into heat. Fluorescent lamps convert 25% of its electrical power into light, with 25% dissipated in the form of radiant heat to the surrounding surfaces and 50% dissipated by convection and conduction. The ballast fluorescent lamp provides more than 25% of the rated lamp in the form of heat to the environment. [Ref. 04].

Besides the radiant heat, emitted light can be absorbed by the atmosphere, increasing the thermal load of the indoor and the need for artificial conditioning cooling, mainly in tropical countries like Brazil. The use of LED lamps reduces the thermal load and electricity consumed by air conditioners to be installed.

Tests were also performed measurement for temperature and radiation in samples of lamps. With a Leslie cube, showed in figure 04. The purpose is to analyze its impact on the cooling system ambient.

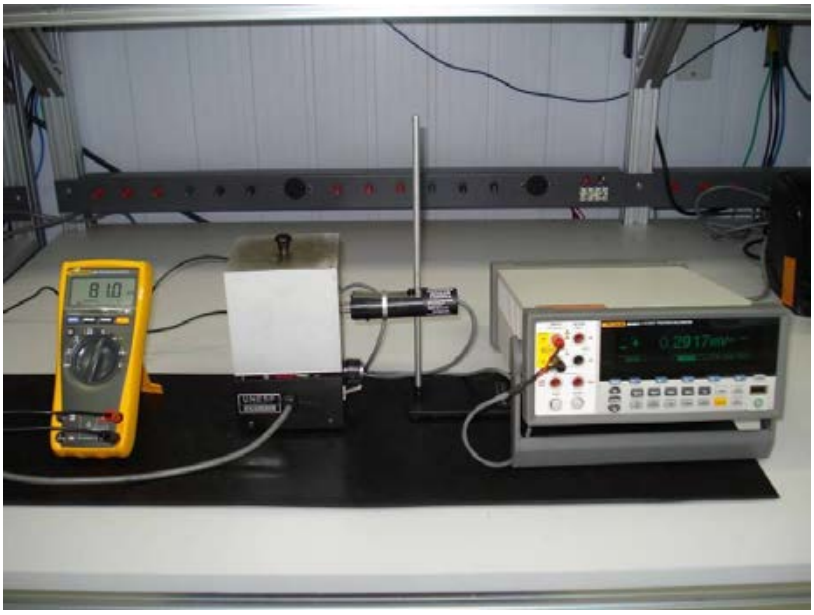


Figure 04:

The results show that, the temperature measured for LED lamp 3W E-27 base was 28.44°C. For CFL of 15W, the temperature measure in the base was 60°C. That more irradiation heat means a higher thermic load for residence an over dimension of conditioning air equipments. Was not possible to performed measurement for other LED lamps because the dimensions of Leslie cub.

3.3. Emission of CO_2 into the atmosphere.

According to report "Emissions of carbon dioxide and methane by the Brazilian hydroelectric reservoirs" of the Ministry of Science and Technology, can be considered the issuance of 24.573 kilograms of CO_2 into the atmosphere per MWh generated.

So the replacement of CFL by LED means a no emission of 27.983 tons of CO_2 into the atmosphere.

For tubular lamps, the CO_2 saved to environment is 70.89 tons.

From the spectrum showed in figure 05. The LED lamp has not emission of infrared radiation and so; do not contribute for greenhouse effect by radiation.

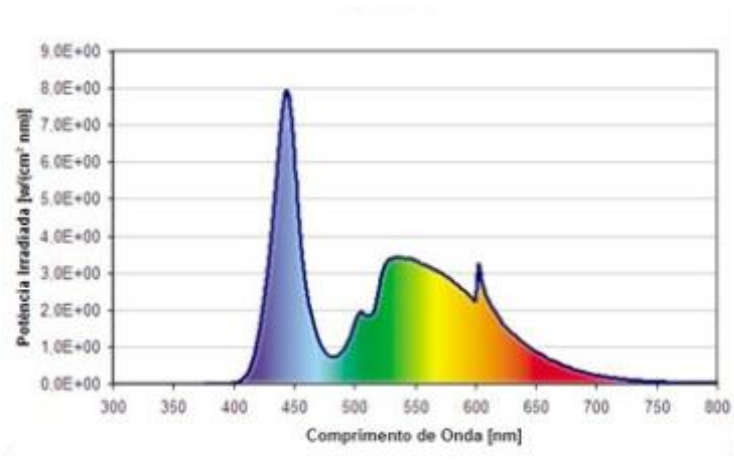


Figure 05: Radiation spectrum of the LED lamp

4. Conclusion

This work demonstrates, based on comparatives analysis in the laboratory, the benefits of using the solid state lighting SSL, or LED technology in residential lighting, replacing traditional technologies currently used, based on tubular fluorescent lamps, and even compact fluorescent lamps, CFLs.

The results presented in the text above show that is possible to save until 4,023.7 GWh in 4 years. Also, it is demonstrated that the replacements give a great environmental improvement decreasing in at less 98.873 tons of CO_2 the greenhouse effect.

The Led technology for residential artificial illumination is actually in development and for future the studies realized in the Laboratory of Efficient Street Lighting System of São Paulo State University, carry out that the efficacy of LEDs is increasing continuously with a very rapid speed. And must be represented a great potential for the use of this technology.

ACKNOWLEDGMENT

To ELETROBRÁS by support to this work.

5. Bibliographical References

[01] Paolo Bertoldi and Bogdan Atanasiu, Residential Lighting Consumption and Saving Potential in the Enlarged EU. European Commission – DG Joint Research Centre, Institute for Environment and Sustainability.

[02] Revista Sustentabilidade, EPE: eficiência energética economizará uma usina Jirau e meia até 2018, 27 de Janeiro de 2010

[03] Apliquim, O uso de mercúrio em lâmpadas e o risco de sua disposição inadequada, 2009

[04] Frota, Anésia Barros. Manual de conforto térmico : arquitetura, urbanismo / Anésia Barros Frota, Sueli Ramos Schiffer.— 5. ed.— São Paulo : Studio Nobel, 2001.

Taming the beast: pushing the efficiency and performance of air conditioner to world's best practice in Australia

Paul Ryan[1], Lloyd Harrington[2]

[1] EnergyConsult, Australia, [2]Energy Efficient Strategies, Australia

Abstract

Energy consumption of air conditioners is rapidly growing in Australia, and they are now posing serious peak load problems on extreme weather days. These factors have prompted a wide range of new policy approaches to deal with these issues.

Australia has a long history of standards and labelling for air conditioning products, with labelling being introduced in 1987, and efficiency standards introduced in 2001. Efficiency standards have been upgraded in 2004, 2006, 2007, 2010 and 2011. New stringent levels have been approved for introduction in late 2011, with further increases flagged for 2014.

The recent changes in 2010 and April 2011 include:

- A reduction in the number of stars for a given efficiency (algorithm regrade) and a new energy label design;
- Increased efficiency standards for all types of air conditioners;
- The introduction of heating efficiency standards for all types of air conditioners;
- The inclusion of off mode and other non-operational power consumption (e.g. crankcase heaters) into the new energy label algorithm in 2010 and efficiency standards from 2011;
- Mandatory minimum power factor requirements in 2011;
- A requirement to report demand response capability in the product registration.

New standards have been developed that will push all products to new levels of efficiency. The minimum permitted annual EER will be 3.1 for most products and as high as 3.66 for some types of split systems. Demand response controls are under consideration in all new air conditioners. These changes will put Australia at the forefront of air conditioner efficiency policy.

Introduction

Mandatory energy rating labels for air conditioners were first introduced in Australia in 1987 in New South Wales and Victoria, with the expansion of the scheme to most Australian states by 1992. In 2000, the energy rating label was re-graded to ensure that the star rating reflected the range of higher efficiency models that had been introduced to the market. In 2001, Minimum Energy Performance Standards (MEPS) were introduced for three-phase air-cooled air conditioners up to 65 kW output capacity. In 2004 the MEPS was extended to single phase air conditioners. At this stage most air conditioners were required to meet MEPS, except for close control, portable and multi-split air conditioners. Subsequently, close control air conditioners were required to meet MEPS in 2009 and multi split air conditioners will be required to meet MEPS 12 months after the publishing of the Australian Standard for testing these equipment, probably in 2012. Plans are underway to address the efficiency of portable air conditioner market, however further research is being undertaken before the release of a regulatory proposal.

The MEPS requirements for single phase air conditioners were increased in 2006 and 2007. In 2008 and 2009, another proposal was developed to further increase the MEPS levels and widen the coverage of the energy rating labels to include the non-operational energy (i.e., standby power and crankcase power). In addition, the MEPS levels for heating Coefficient of Performance (COP) of reverse cycle air conditioners were developed. This proposal was accepted by the Australian Federal and State Governments in 2009 and the new MEPS levels were staged to take effect in April 2010, with the increased EER and COP requirements and April 2011 for non-operational energy. Other requirements introduced included mandatory minimum power factor and a requirement to report the demand response capability in the product registration[1].

The MEPS levels approved in December 2010 by the Ministerial Council of Energy (MCE),comprising ministers responsible for energy from all states and territories, has again increased the MEPS levels to 3.1 for most products and as high as 3.66 for some types of split systems from October 2011. These levels are among the highest MEPS requirements in the world and are applied to the Annual EER and COP, which includes the operational and non-operational energy consumption[2]. These developments are described in the following sections.

Broad Measures to Improve the MEPS and Labelling Program

Annual Energy Efficiency Ratio and COP

Since March 2006, it has been mandatory for new registrations for MEPS and energy labelling to report data on the power consumption in standby and off modes as well as information on the power consumption of crank case heaters (where applicable).There are about 1850 approved records that contain this data in 2008 (about two thirds of approved registrations). Around 20% of records with the data entered have a crankcase heater, around 85% consume energy in standby, and 55% consume energy in off mode, as shown in Table 1

Table 1: Air Conditioner Energy Consumption Values for Standby and Crankcase Heaters

Description	Crankcase Heater (Y/N)	Average Value Watts	Sample Size N =
Crankcase Heater	Y	50.18	359
Standby	Y	54.17	355
Standby	N	8.76	1205
Off	Y	55.58	313
Off	N	8.33	710

This data shows that the power levels in off mode, standby mode and for crankcase heaters is substantial in some cases. At a power consumption of 50 Watts, the annual energy consumption would be 388 kWh per year (assuming 1000 hours usage, or7760 hours not operating), which is the equivalent energy consumption a large new household refrigerator. Prior to 2010, there were no requirements regarding this energy consumption in terms of an impact on energy labelling or MEPS which use operational efficiency and ignore any power consumption when not in use.

To examine the impact of standby and crankcase heater energy consumption on total operational energy, it is necessary to assume a usage pattern for the product. The total operational energy consumption of an air conditioner is directly proportional to assumed hours of operation (at rated capacity), but standby and crankcase energy consumption will be less affected by assumed hours (as this is proportional to 8760minus the assumed hours of operation). For air conditioners with a larger input power(larger compressors) the impact of crankcase heaters and standby will also be smaller(in a relative sense, although the absolute energy is still substantial). Figure 1 shows the impact of this non-operation energy consumption on a new formula that measures the equivalent “Annual Energy Efficiency Ratio” or Annual EER (AEER). This formula is required to be used to represent the efficiency of both cooling EER and heating COP for energy labelling from April 2010 and MEPS requirements from April 2011. The new Annual EER is calculated as follows:

$$[\text{Tested output} \times 2000] / [\text{Tested input} \times 2000 + \text{Non-operational Power} \times 6.760]$$

Where:

Tested output is the measured output in kW for cooling*
Tested input is the measured input in kW for cooling*
Non-operational power is the maximum of off mode, standby mode or crankcase heater power, in Watts
*except for heating only products where it is based in heating output

This equation assumes that the product is used for 2000 hours for heating or cooling or a combination of both modes (i.e. non-operating period is 6760 hours per year for all products). For reverse cycle products, the heating and cooling calculation is done using the same assumption, which effectively shares the non-operational energy over both modes.

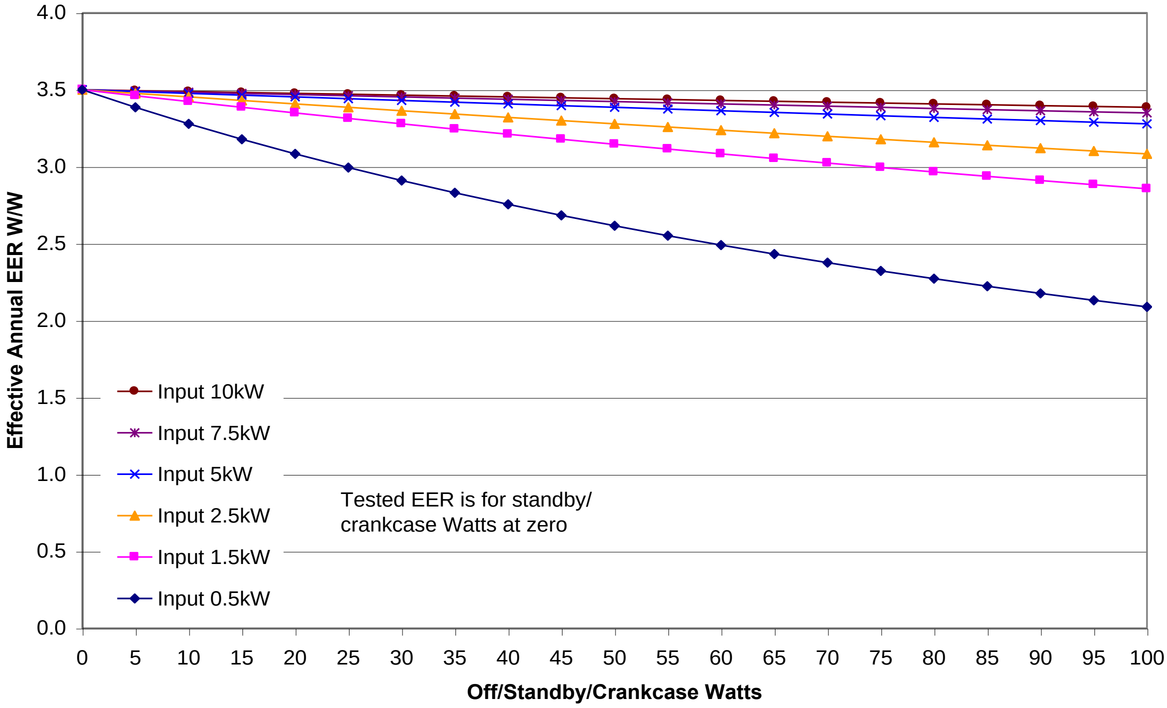


Figure 1: Impact of Standby or Crankcase energy use on Annual EER: Based on 2000 hours operation per annum

Air Conditioner Energy Rating Label Re-grade

In 2008 results of the energy labelling program demonstrated that the market is tending towards a majority of products having star ratings that are bunched around the range of 3.5 to 5 stars. Market research demonstrates that consumers use the star rating labels in purchase decisions and that it also provides suppliers with a means to differentiate their product with a view to increasing market share. For the labelling program to continue to be an effective tool for all stakeholders, a change in the star rating algorithm was required.

While MEPS and labelling are not directly linked, any action regarding one will influence the other. Labelling has encouraged more efficient models onto the market and allows consumers to identify efficient models, while MEPS has removed the worst performing products. Increasingly stringent MEPS has resulted in a market whereby most products with lower star ratings under the older algorithm have been eliminated, leaving star ratings bunched for air conditioners, predominately with a rating of between 3.5 and 5 stars. Data in 2008 showed a significant number of models that rate beyond the current maximum scale of 6 stars. Studies have shown that more than 90% of consumers can recall the energy label unprompted, nearly 9 out of 10 consumers use the information on the energy label when buying an appliance and 75% say that the energy rating label is very important in the appliance purchasing process [3]. The continuing impact of the energy rating label as a driver of increasing energy efficiency for the air conditioner market depends on several factors, including:

- A reasonable spread of star ratings on the market for all classes and capacities, so buyers are motivated to seek out more efficient options where available;

- Sufficient space at the top of the energy rating scale so that suppliers can exploit the commercial value of introducing more efficient products (allowing them to strive for higher star ratings which will remain available for a long period);
- A good match between energy consumption under test conditions and energy consumption under use conditions (at least in a comparative sense, if not absolutely in all cases); and
- That both suppliers and consumers have continued confidence in the integrity of the program.

The aim of re-grading the energy labelling algorithm was to implement energy labelling for air conditioners that is both technically sound and that provides a solid basis for the rating of products in Australia and New Zealand over at least the next 5 to 10 years. Figure 2 shows the star ratings of the energy rating label algorithm introduced in 2000. This figure shows that many products are exceeding the 6 star maximum for the label.

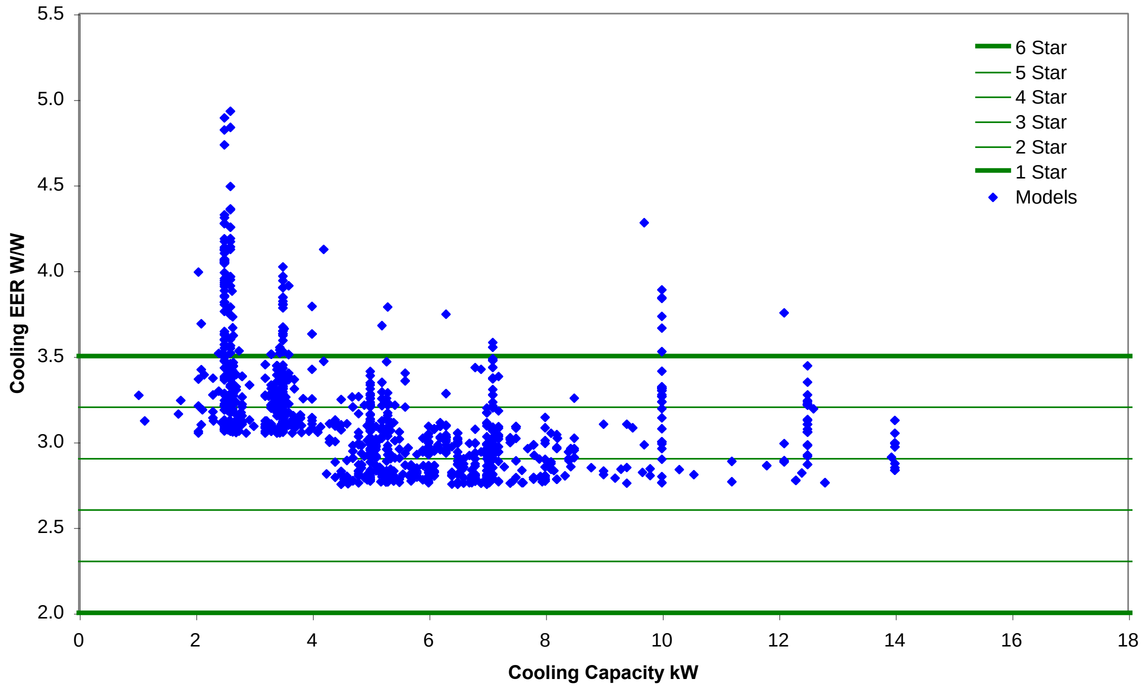


Figure 2: Star Ratings for Non-ducted Spit System Air Conditioners and Cooling EER – 2008 Registration Data

The new star rating algorithms for both heating and cooling were introduced in 2010 and utilise the new annual EER and annual COP as determined earlier. Figure 3 shows the effect of the regraded algorithm for air conditioners. For example, a product that rates 2.5 stars for heating in 2000 will rate 1 star under the new algorithm. Similarly, a product that rates 6 stars for cooling in 2000 will rate 2.5 stars under the new algorithm.

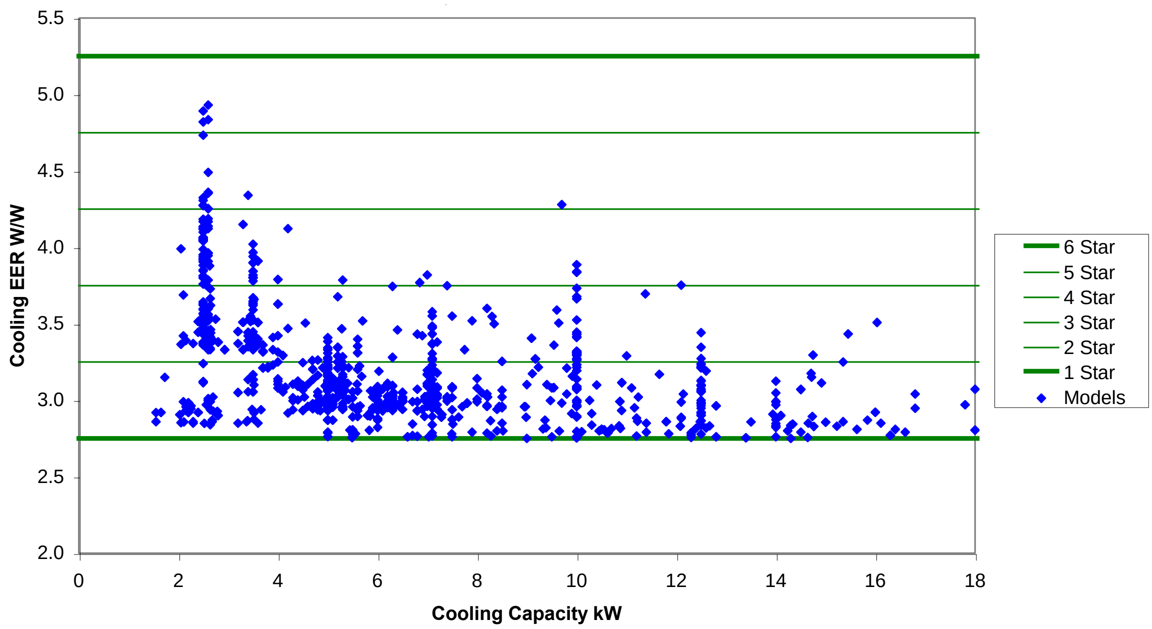


Figure 3: Star Ratings with 2010 Energy Labelling Algorithm for Air Conditioners – Cooling using 2008 Registration Data

Heating Efficiency Standards for all Types of Air Conditioners

Since MEPS was first introduced for three phase air conditioners in 2001, there has been no minimum requirement for heating mode efficiency for reverse cycle or heating only products. In a well designed air conditioner which is optimised for both heating and cooling operation, the technical efficiency under heating mode is usually slightly higher in heating mode as the energy from the compressor operation (the heat resulting from the compression of the refrigerant) can contribute to the overall heat load going into the conditioned space, which in turn increases the overall COP of the system. For a given air conditioner compressor, the relative performance of heating and cooling modes can be altered by changing the relative size of the indoor and outdoor evaporator/condenser units and also to some degree by the configuration of the refrigeration values and other controls.

It would appear that the introduction of stringent MEPS levels for cooling mode has resulted in an overall substantial improvement in heating mode efficiency of most products on the market, which is expected. However, in 2008 there was concern about the performance of a small minority of products where it appears that the heating mode performance has been downgraded substantially in order to meet the MEPS levels for cooling mode.

Figure 4 shows the cooling EER versus the heating COP for approved single-phase non ducted split system air conditioners in 2008. The vast majority of products lie above the red line which means that their heating performance is better than their cooling performance (expressed as Watts/Watt). However, it can be seen that there are a number of products that fall well below the red line, which means that their heating performance is poor and in all likelihood has been compromised in some way to meet the minimum efficiency (MEPS) requirements for cooling. If consumers are relying on MEPS to guarantee minimum cooling efficiency, or where MEPS is introduced to address market failures, it is reasonable that some equivalent guaranteed efficiency for heating performance is also applied as part of the MEPS regime. The minimum efficiency requirements for heating COP were introduced in 2010 at the same levels as the cooling EER to offer a safety net of consumer protection for heating performance.

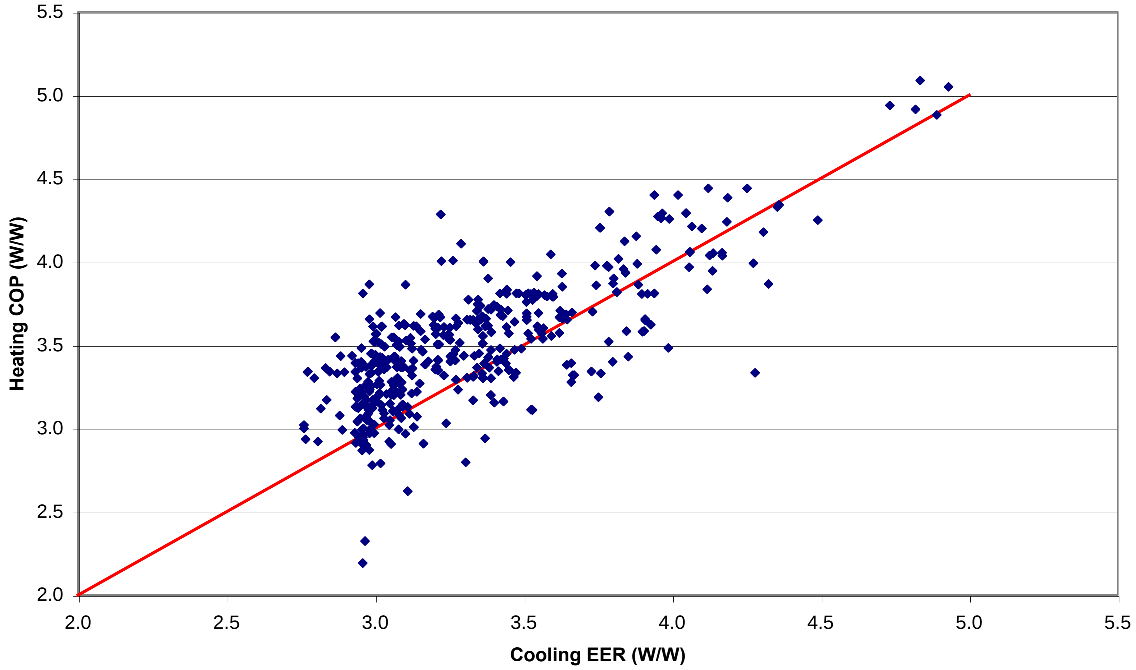


Figure 4: Cooling EER versus Heating COP for Single Phase Non-ducted Split System Air Conditioners

Minimum Power Factor Requirements

Since March 2006, it has been mandatory for new registrations for MEPS and energy labelling to report data on the power factor during operation. The issue of power factor is often raised in the context of peak load and utility distribution issues – a poor power factor increases the current required (for a given input power) which can affect the sizing of distribution transformers and other elements of the distribution system. Given that many Australian states now have summer peak loads and this is driven by air conditioning loads, some consideration of power factor is a potentially important issue, mostly from a peak load perspective.

The power factor of an AC electric power system is defined as the ratio of the real or active power (the energy over a particular time) to the apparent power (the product of the current and voltage of the circuit); the lower the ratio, the lower the power factor. Currently there is no specific requirement for the allowable power factor for air conditioners. Figure 5 shows the power factors for approved air conditioners for cooling modes. It can be seen that the vast majority of units have a power factor greater than 0.9, but units that claim a power factor of exactly 1 are perhaps not correct. Units claiming less than 0.85 are of some concern for the reasons listed above.

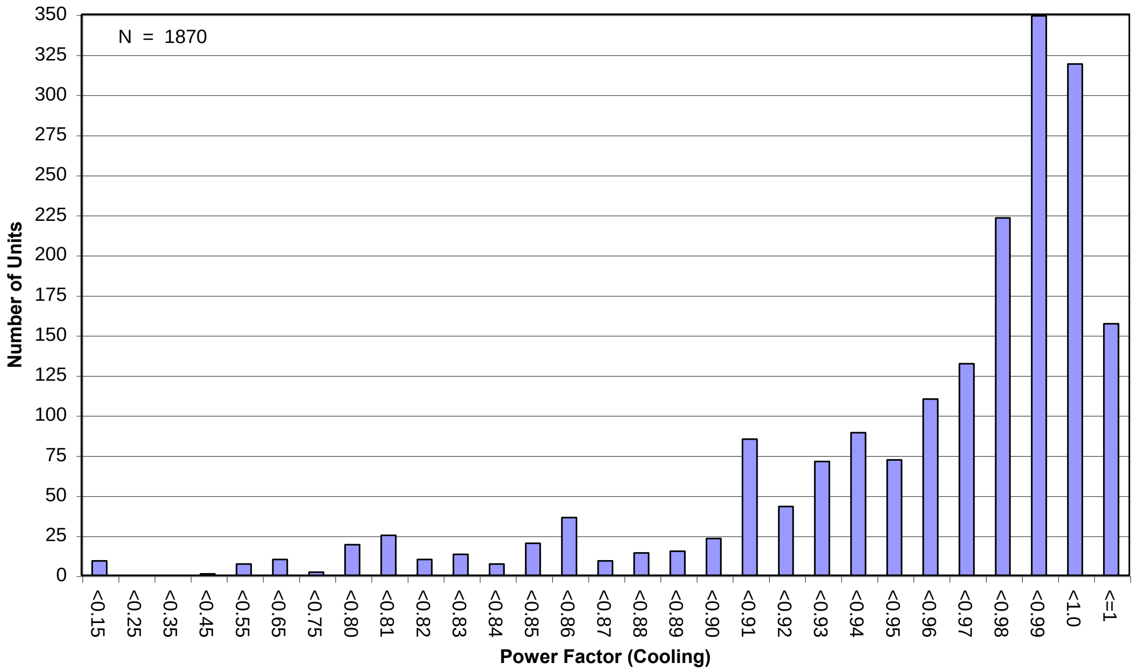


Figure 5: Power Factor (Cooling) for Approved Air Conditioners in 2008

The April 2011 MEPS requirements include a minimum power factor for heating and cooling operation at rated capacity of 0.85 as a minimum performance requirement for all air conditioners.

Reporting Demand Response Capability

Air conditioners play a large role in peak load issues experienced during times of high electricity demand. Number studies have shown that air conditioners can account for 30% to 50% of total state demand on days of extreme weather [4]. In order to reduce the capital costs of providing distribution infrastructure that will only be utilised at peak times, electricity suppliers throughout Australia are exploring programs to encourage users to manage their electricity loads at those times. The essential elements of these programs are:

- Electricity pricing structures or other means to encourage customer to take action at the time of high loads on the supply system (often called ‘critical peak’ periods)
- Convenient ways for customers to respond. Signalling changing prices to consumers, e.g. via ‘in-home displays’ has been found to have a limited impact, in the absence of means for consumers to pre-select automated ‘demand responses’ or to voluntarily enter direct load control agreements with their electricity suppliers.

Demand Response is the automated alteration of an electrical product’s normal mode of operation in response to an initiating signal originating from or defined by a remote agent. At present, some air conditioners have a latent demand response capability in their control software, but low-cost means to realise this capability have not so far been available. A forthcoming standard will define the physical connections and communications protocols necessary to realise the demand response modes set out in Table 2

Table 2: Proposed Demand Response Modes, AS4755.3.1

Demand Response Mode	Description of Operation in this Mode
DRM 1	Compressor off
DRM 2	The air conditioner continues to cool or heat during the demand response event, but the energy consumed by the air conditioner in a

	half hour period is not more than 50% of the total energy that would be consumed if operating at the rated capacity in a half hour period
DRM 3	The air conditioner continues to cool or heat during the demand response event, but the energy consumed by the air conditioner in a half hour period is not more than 75% of the total energy that would be consumed if operating at the rated capacity in a half hour period

The potential net benefit of introducing demand response capability into between7.5% and 15% of the air conditioner stock, in the context of a national rollout of smart meters, has recently been estimated at between $250 million and $756 million NPV[5]. However, the standard demand response capabilities envisaged in the above table could also be introduced without the presence of smart meters, or in advance of later installation of such meters. As not all models of air conditioner will have demand response capability, or the same level of demand response capability, it is necessary to provide a convenient way for buyers to identify such products prior to and at the time of purchase. Therefore, from 2010,it is now mandatory to report demand response capability in the product registration and display this on the energy rating label.

Increased MEPS Levels

MEPS were first introduced for three phase air conditioners up to 65 kW output capacity in 2001, and later increased in 2007, as shown inFigure 6. MEPS for most single phase air conditioners were introduced in 2004 and increased in 2006 and 2010, with the example of non-ducted split type air conditioners shown in Figure 7. The MEPS levels for all air conditioners were based on the cooling Energy Efficiency Ratio (EER) until 2010.

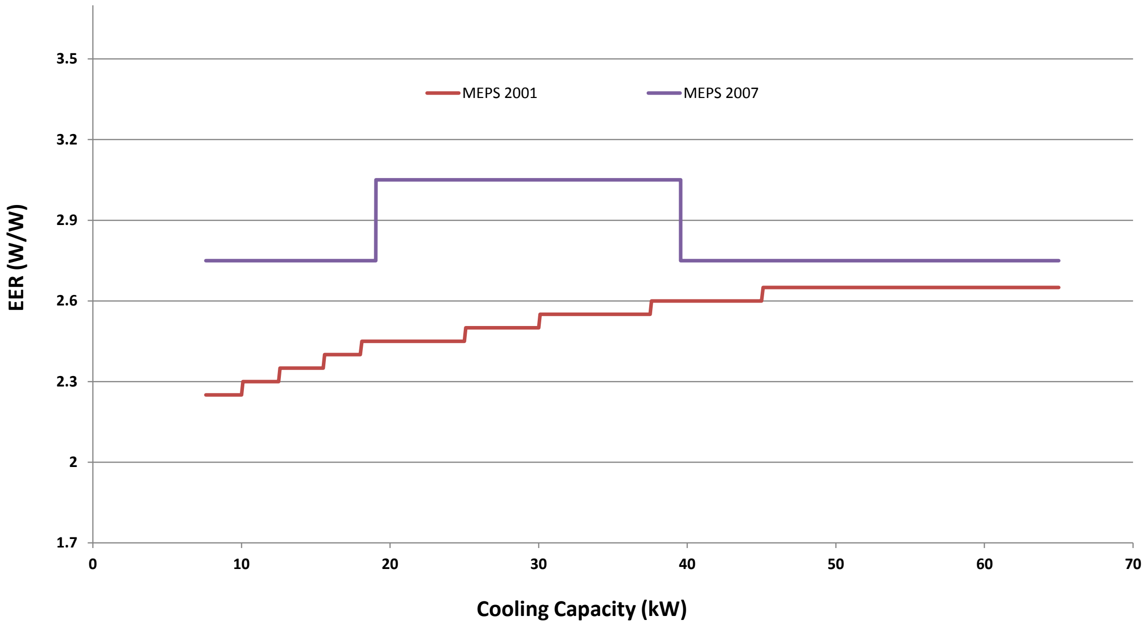


Figure 6: Three Phase Air conditioner MEPS Levels 2001 to 2007

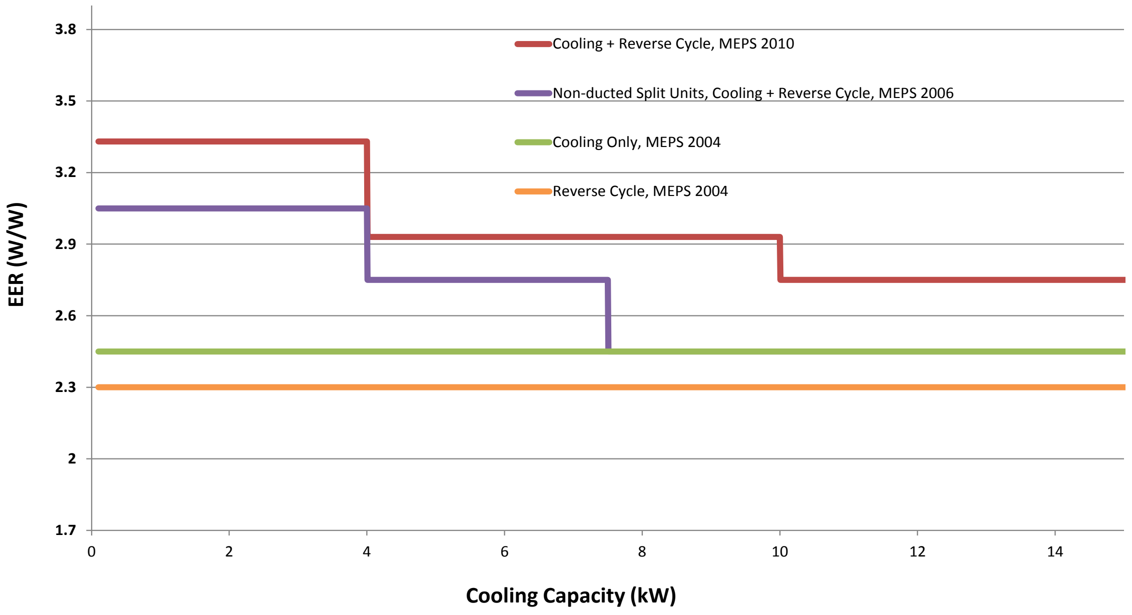


Figure 7: Non-ducted Split Air Conditioner MEPS Levels 2004 to 2010

In April 2011, the MEPS levels were changed for all air conditioners to be measured as the Annual EER (AEER) and Annual COP (ACOP), which includes the non-operational energy of associated with standby power and crankcase heaters. The levels were increased by the Australian Government by an average of 10% from October 2011, with the new levels and the recent April 2011 levels shown in Table 3[6]. These MEPS levels are now approaching the most stringent in the world, with only the USA and Canada requiring a higher EER for units greater than 19 kW.

Table 3: MEPS Levels for April 2011 and October 2011

Product Description	Minimum AEER and/or ACOP 1 Apr 2011	Minimum AEER and/or ACOP 1 Oct 2011
Non ducted unitary – all types, < 10kW, all phases	2.84	3.10
Non ducted unitary – all types, 10kW to <19kW, all phases	2.75	3.10
Non ducted split systems – all types, < 4kW, all phases	3.33	3.66
Non ducted split systems – all types, 4kW to <10kW, all	2.93	3.22
Non ducted split systems – all types, 10kW to <19kW, all	2.75	3.10
Ducted systems – all types, <19kW, all phases	2.75	3.10
All configurations – all types, 19kW to 39kW, all phases	3.05	3.10
All configurations – all types, >39kW to 65kW, all phases	2.75	2.90

The overall increase in MEPS level in October 2011 is predicted to remove 69% of models that were registered for sale in Australia in December 2010. The greatest impact will be with single phase ducted units where 80 to 84% of products are currently non-compliant as show in Table 4

Table 4: Percent Non-compliant Models with Proposed Oct 2011 MEPS

Phase	Configuration 1	Configuration 2	Non-Compliant Models	Compliant Models	Total Models	Percent Non-Compliant
Single	Ducted	Packaged	4	1	5	80%
		Single Split System	175	33	208	84%

	Ducted Total		179	34	213	84%
	Non Ducted	Double/Triple Split	3		3	100%
		Single Split System	463	244	707	65%
		Window Wall	60	48	108	56%
	Non Ducted Total		526	292	818	64%
Single Total			705	326	1,031	68%
Three	Ducted	Packaged	75	28	103	73%
		Single Split System	116	44	160	73%
	Ducted Total		191	72	263	73%
	Non Ducted	Single Split System	15	7	22	68%
	Non Ducted Total		15	7	22	68%
Three Total			206	79	285	72%
Grand Total			911	405	1,316	69%

For non-ducted split air conditioners, Figure 8 shows the Annual EER of models verses the MEPS introduced in April 2011 and the MEPS proposed for October 2011. Approximately 65% of models currently registered in December 2010 will not be compliant with the October 2011 MEPS levels.

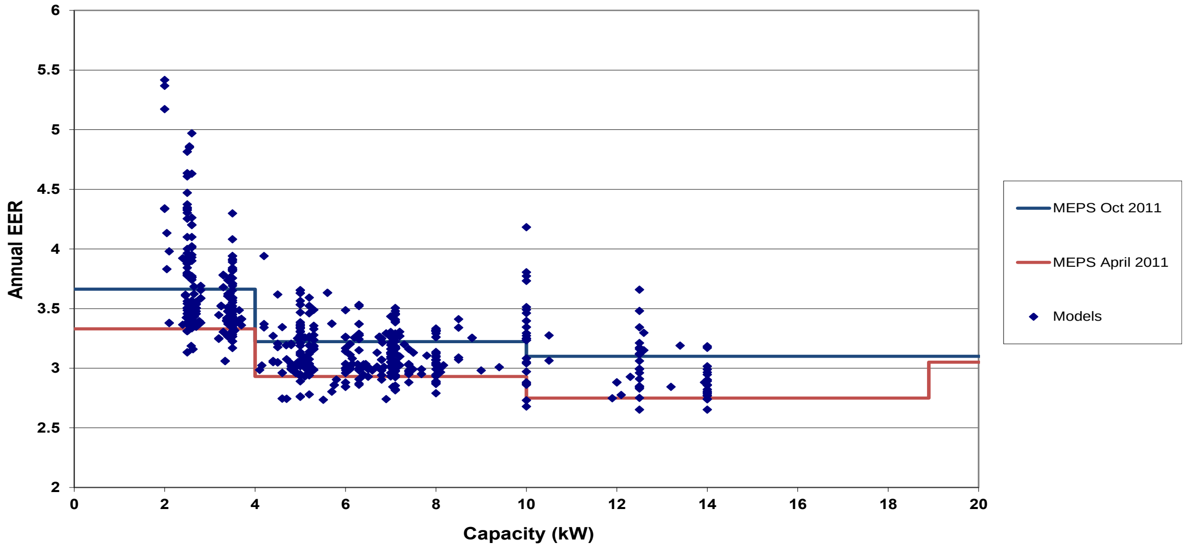


Figure 8: Non-ducted Split Air Conditioners Models and MEPS Apr/Oct 2011 (Dec 2010 Registration Data)

The MEPS levels have increased over the last decade by as much as 60% in some categories and this has been proven to drive the efficiency of air conditioners in Australia. A study[7] by EnergyConsult in 2010 has shown the MEPS introduced in 2004 and 2006/7 have increased the average sales weighted efficiency of split air conditioners by 3.8% pa and 5.5% pa respectively. This compares to the average efficiency increases of 0.5% pa over the period from 1988 to 2002 before the introduction of MEPS, as shown in Figure 9. This figure was developed before the October 2011 MEPS levels were announced and hence does not include the effects of these latest MEPS.

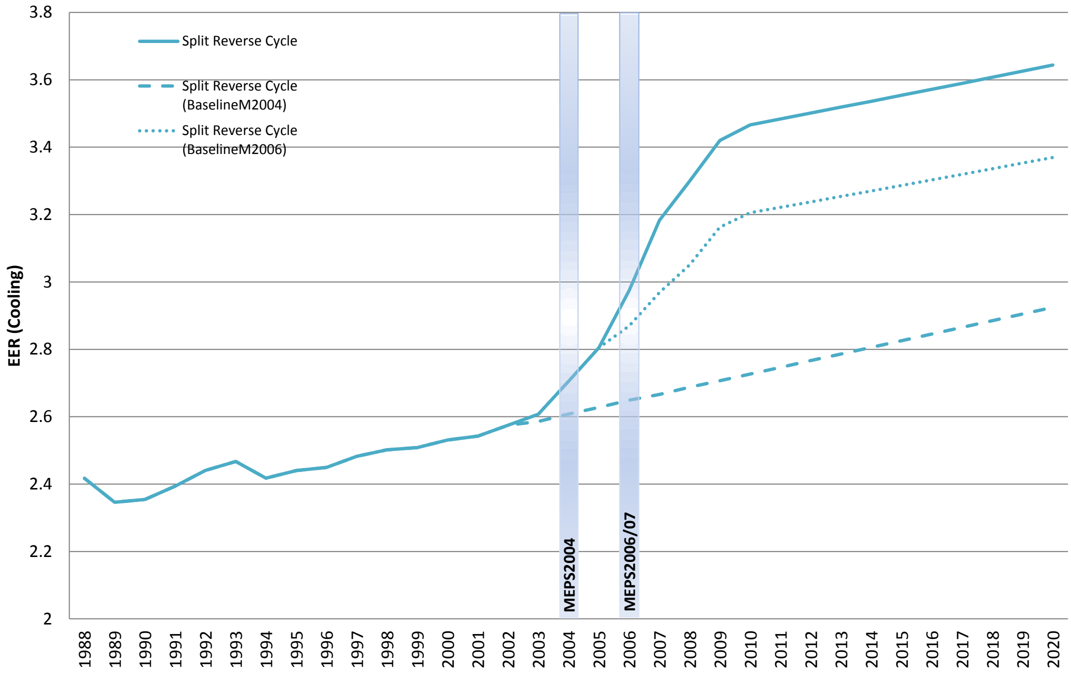


Figure 9: Baseline and Policy Trends for Energy Efficiency Ratio (EER): Split System Air Conditioners- Reverse Cycle

Conclusions

The MEPS program in Australia has clearly contributed to the increase in average efficiency of air conditioners and is still a key component of government policy, as demonstrated by the recent increase in MEPS levels proposed for October 2011, only 6 months after the last increase. In addition the MEPS and energy labelling program has been refined and improved by changes to the measurement approach to include non-operational energy use and power factor requirements. The program has been expanded to include minimum heating efficiency requirements in 2010 and reporting of demand response capabilities in 2011. It is clear from the changes in average efficiency since the introduction of MEPS that

To ensure that the energy labelling program remains relevant to consumers and suppliers, regular re-grading of the star rating scale is required, with the most recent re-grading occurring in 2010. Previously the scale was re-graded in 2001. This regular re-assessment of the labelling program is needed to ensure adequate spacing of products with various levels of efficiency and those models are not all “bunched” at the top of the scale. The major improvement in efficiency over the last decade, mostly due the MEPS, means that energy labelling program has to be regularly reviewed.

References

[1] *Air Conditioner MEPS and Energy Labelling - Decision Regulatory Impact Statement*, prepared by Energy Efficient Strategies, April 2009, Prepared for Department of Climate Change & Energy Efficiency, Available from http://www.energyrating.gov.au/library/details200921-ac-decision-ris.html

[2] *Decision Regulatory Impact Statement: Minimum Energy Performance Standards for Air Conditioners: 2011* prepared by EnergyConsult for the Equipment Energy Efficiency Committee under the auspices of the Ministerial Council on Energy, Canberra, Australia, December 2010

[3] *Appliance Performance Labelling in Australia and New Zealand; Final Report on a Major Quantitative Study among Consumers and Retailers on the Labelling of Household Appliances*, by Artcraft Research for E3 & the Australian Greenhouse Office, Department of the Environment and Heritage. Available from www.energyrating.gov.au in the electronic library

[4] *Electrical Peak Load Analysis Victoria 1999 – 2003*, by Energy Efficient Strategies for the Victorian Energy Networks Corporation (VENCORP) and the Australian Greenhouse Office. Available from www.energyrating.gov.au in the electronic library.

[5] *Cost-Benefit Analysis of Options for a National Smart Meter Roll Out (Phase Two – Regional and Detailed Analysis)*, Consultation Regulatory Impact Statement, Standing Committee Officials of the Ministerial Council on Energy, April 2008.

[6] Air Conditioner Stakeholder letter concerning details of the New Requirements for Air Conditioners, Department of Climate Change & Energy Efficiency, Australian Government, December 2010 available from http://www.energyrating.gov.au/pubs/ac-stakeholder-letter-24-12-10.pdf

[7] *Evaluation of Energy Efficiency Policy Measures for Household Air Conditioners in Australia* (Report 2010/12). Prepared by EnergyConsult for Department of Climate Change & Energy Efficiency, Available fromwww.energyrating.gov.auin the electronic library.

Overview of Current U.S. Regulatory Activity Impacting the Energy Consumption of Residential Air Conditioning and Heating Equipment

Karim Amrane
Air-Conditioning, Heating, and Refrigeration Institute

Abstract

The energy consumption of residential air conditioning and heating equipment has been regulated in the United States for over 30 years. However, in the last two years, there has been an unprecedented level of regulatory activity on energy conservation standards at the state and federal levels. A review of recently completed and on-going federal rulemakings at the U.S Department of Energy (DOE) on residential cooling and heating products will be provided. A particular emphasis will be put on the efforts to establish for the first time in the U.S. regional energy conservation standards for residential air conditioners, heat pumps and furnaces. Finally, tax incentives for very efficient residential air conditioning and heating products will be reviewed

Introduction

The annual energy consumption in residential buildings in 2006 accounted for close to 21% or 21 quads (6.12 x 10^{12} kWh) of the total annual U.S. primary energy consumption, more than the commercial building sector [1]. About half of the primary annual energy consumption (e.g.; 52%) was used in space heating, space cooling and water heating applications costing consumers over $125 Billion in 2006.

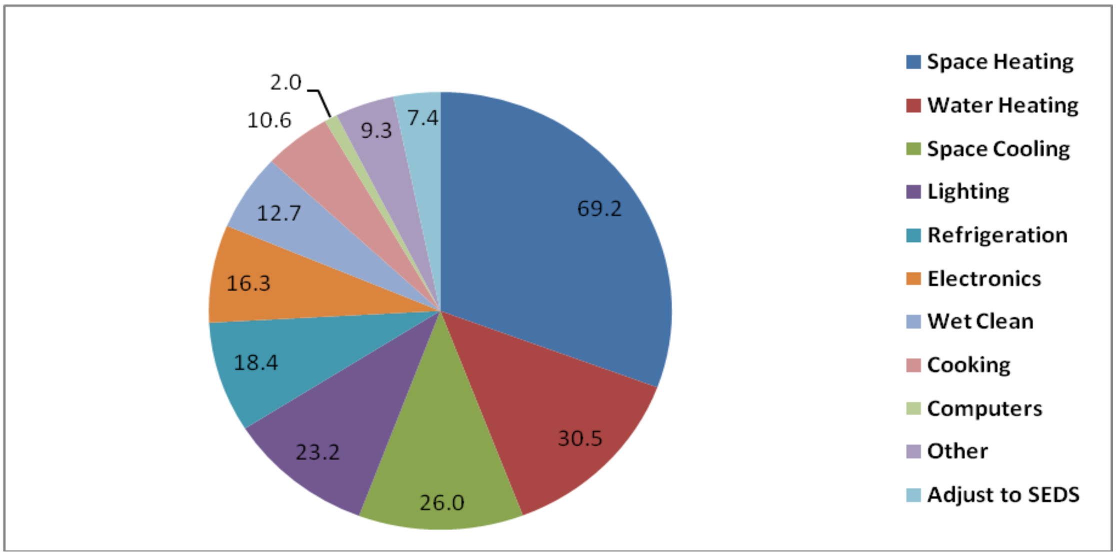


Figure 1: 2006 Residential Energy End-Use Expenditures ($2006 Billion – *Source EIA [1]*)

Minimum energy efficiency standards and manufacturer investments to meet and exceed them have led to enormous efficiency improvements since they were first implemented in the U.S. in the late nineteen eighties. For example, the energy efficiency of central air conditioners has improved by more than 60%, from roughly 8 SEER[1] (pre-1992) to 13 (effective January 23, 2006). All together, national standards on appliances and equipment have saved an estimated 2.7 quads (0.79×10^{12} kWh) of electricity source energy by 2010 [2].

However, despites the overall success of the federal appliance energy efficiency program, the U.S. Department of Energy (DOE) stepped up its regulatory activity. During the past two years, DOE issued or codified new efficiency standards for more than twenty different products. These new standards are expected to save consumers between $250 and $300 billion on their energy bills through 2030 [3].

This paper reviews recently completed and on-going federal rulemakings on residential cooling and heating products. The consensus agreement reached between energy efficiency advocacy groups and manufacturers that would establish for the first time in the U.S. regional energy conservation standards for residential air conditioners and furnaces will be discussed in detail. This paper also reviews tax incentive programs that were recently put in place to promote the sale of very efficient residential air conditioning and heating products.

History of Equipment Energy Efficiency Standards

The first federal energy conservation standards for residential heating, cooling and water heating products were established by the U.S. Congress through the enactment of the National Appliance Energy Conservation Act (NAECA) in 1987 [4]. This legislation, which amended the Energy Policy and Conservation Act (EPCA), was the product of negotiations between manufacturer trade associations, energy efficiency advocates and certain state government agencies, particularly the California Energy Commission. Prior to NAECA, the energy efficiency of residential products was not federally regulated. In the mid seventies, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published ASHRAE standard 90 [5] which established voluntary minimum energy efficiency standards for a variety of residential and commercial heating, ventilating and air conditioning products, including residential unitary air conditioners, chillers, packaged terminal equipment, and water-source heat pumps. However, in 1976, the state of California prescribed the first mandatory efficiency standards for residential products such as refrigerators, freezers, room air conditioners, and central air conditioners. Soon after, other states introduced their own energy efficiency standard requirements which created a patchwork of state standards that became very burdensome to the industry.

The enactment of NAECA put an end to state standards on federally-covered equipment because of provisions in the legislation that specifically preempted states and local jurisdictions from requiring equipment with more stringent efficiencies than those established by DOE. The minimum federal energy conservation standards prescribed by NAECA for residential air conditioners, furnaces, water heater, direct heating equipment and pool heaters are shown in Table 1. Depending on the product class, these standards became effective between January 1, 1990 and January 1, 1993.

NAECA also required DOE to update the standards and publish final rules by various dates to determine whether the standards should be amended. However, DOE missed most of the deadlines and in 2005, 14 states and various other entities brought suit alleging that DOE had failed to comply with statutory deadlines and other requirements. In 2006, DOE entered into a consent decree under which it agreed to publish final rules for 22 product categories by specific deadlines [6].

[1] Seasonal Energy Efficiency Ratio (Btu/W.h) tested according to AHRI Standard 210/240

According to EPCA, any new or amended standard must be designed so as to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. In order to determine economic justification, DOE must demonstrate that the benefits of the proposed standard exceed its burdens by weighing several factors including (1) the economic impact of the standard on manufacturers and consumers; (2) the savings in operating costs throughout the estimated average life of the covered product; (3) the total projected amount of energy savings likely to result directly from the imposition of the standard; (4) any lessening of the utility or the performance of the covered products likely to result from the imposition of the

Table 1: Minimum Federal Energy Conservation Standards Enacted by the National Appliance Energy Conservation Act (NAECA) of 1987

Product Class	**Efficiency**		**Effective Date**
Residential central air conditioners and heat pumps < 65,000 Btu/h	Seasonal Energy Efficiency Ratio (SEER)	Heating Seasonal Performance Factor (HSPF)	
Split systems	10	6.8	1/1/1992
Single package systems	9.7	6.6	1/1/1993
Water Heaters	Energy Factor		
Gas water heater	0.62-(.0019 x rated volume in gallons)		1/1/1990
Oil water heater	0.59-(.0019 x rated volume in gallons)		1/1/1990
Electric water heater	0.95-(.00132 x rated volume in gallons)		1/1/1990
	0.93-(.00132 x rated volume in gallons)		4/15/1991
Direct Heating Equipment	Annual Fuel Utilization Efficiency (AFUE)		1/1/1990
Gas wall fan type			
up to 42,000 Btu/h	75%		
over 42,000 Btu/h	76%		
Gas wall gravity type			
up to 10,000 Btu/h	59%		
over 10,000 up to 12,000 Btu/h	60%		
over 12,000 up to 15,000 Btu/h	61%		
over 15,000 up to 19,000 Btu/h	62%		
over 19,000 up to 27,000 Btu/h	63%		
over 27,000 up to 46,000 Btu/h	64%		
over 46,000 Btu/h	65%		
Gas floor			
up to 37,000 Btu/h	56%		
over 37,000 Btu/h	57%		
Gas room			
up to 18,000 Btu/h	57%		
over 18,000 up to 20,000 Btu/h	58%		
over 20,000 up to 27,000 Btu/h	63%		
over 27,000 up to 46,000 Btu/h	64%		
over 46,000 Btu/h	65%		
Pool Heaters	Thermal Efficiency		
Gas fired	78%		1/1/1990
Residential furnaces < 225,000 Btu/h (66 kW)	Annual Fuel Utilization Efficiency (AFUE)		
Furnaces (excluding classes noted below)	78%		1/1/1992

Mobile Home Furnaces	75%	9/1/1990
Small furnaces < 45,000 Btu/h (13.2 kW)		
(A) Weatherized	78%	1/1/1992
(B) Non-weatherized	78%	1/1/1992
Boilers (excluding gas steam)	80%	1/1/1992
Gas steam boilers	75%	1/1/1992

standard; (5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard; (6) the need for national energy and water conservation; and (7) other factors the Secretary of Energy considers relevant.

Current Regulatory Activities

Residential Water Heaters, Direct Heating Equipment and Pool Heaters

DOE issued a notice of proposed rulemaking (NOPR) in 1994 proposing to amend the energy conservation standards for direct heating equipment and pool heaters. However, the Department of Interior and Related Agencies Appropriations Act for Fiscal Year 1996 provided for a moratorium on proposing or issuing final rules for equipment standards rulemakings for the remainder of fiscal year 1996, preventing DOE from issuing a final rule [7]. On the other hand, the minimum federal energy conservation standards for residential water heaters were first revised in 2001. These standards are shown in Table 2 and became effective on January 20, 2004. Potential energy savings from these standards were estimated by DOE at 4.6 quads (1.35 x 10^{12} kWh) over 26 years [8].

Table 2: First Revision of Minimum Federal Energy Conservation Standards for Water Heaters

Product Class	Efficiency	Effective Date
Water Heaters	Energy Factor	1/20/2004
Gas water heater	0.67-(.0019 x rated volume in gallons)	
Oil water heater	0.59-(.0019 x rated volume in gallons)	
Electric water heater	0.97-(.00132 x rated volume in gallons)	
Tabletop water heater	0.93-(.00132 x rated volume in gallons)	
Instantaneous gas water heater	0.62-(.0019 x rated volume in gallons)	
Instantaneous electric water heater	0.93-(.00132 x rated volume in gallons)	

In 2007, DOE started a new rulemaking to update the minimum federal energy conservation standards for direct heating equipment, pool heaters and residential water heaters. A final rule amending the standards was published in April 2010 [9]. Table 3 lists the revised energy conservation standards. These standards will become effective on April 16, 2013 for direct heating equipment and pool heaters; and April 16, 2015 for water heaters. Of significance is the fact that the energy efficiency of residential water heaters over 55 gallons in storage capacity will require the use of condensing and heat pump technologies for gas and electric water heaters respectively. According to DOE, the new standards will save approximately 2.8 quads (0.79 x 10^{12} kWh) over a 30-year period, with most of the savings coming from the new water heater standards.

Residential Central Air Conditioners, Heat Pumps and Furnaces

The federal energy conservation standards for residential central air conditioners and heat pumps were last revised in 2001. However the rulemaking was very controversial and was challenged in court. The standards became effective in 2006. However, a new rulemaking started in 2008 and will be completed in June 2011. Similarly, the final rule updating the minimum federal energy conservation standards for residential furnaces was published in November 2007 and was immediately challenged in court as the standards adopted by DOE were believed not to be stringent enough. DOE filed a motion for voluntary reconsideration of the furnace finale rule. The motion was granted by the court and DOE announced that a final rule will be published in May 2011. The federal energy conservation standards for central air conditioners, heat pumps and furnaces are listed in Table 4.

Table 3: Latest Revisions to the Federal Energy Conservation Standards for Direct Heating Equipment, Pool Heaters and Residential Water Heaters

Product Class	**Efficiency**	**Effective Date**
Water Heaters	Energy Factor	4/16/2015
Gas water heater, volume ≤ 55 gallons	0.675-(.0015 x rated volume in gallons)	
volume > 55 gallons	0.8012-(0.00078 x rated volume in gallons)	
Oil water heater	0.68-(.0019 x rated volume in gallons)	
Electric water heater, volume ≤ 55 gallons	0.96-(.0003 x rated volume in gallons)	
volume > 55 gallons	2.057-(.00113 x rated volume in gallons)	
Tabletop water heater	0.93-(.00132 x rated volume in gallons)	
Instantaneous gas water heater	0.82-(.0019 x rated volume in gallons)	
Instantaneous electric water heater	0.93-(.00132 x rated volume in gallons)	
Direct Heating Equipment	Annual Fuel Utilization Efficiency (AFUE)	4/16/2013
Gas wall fan type		
up to 42,000 Btu/h	75%	
over 42,000 Btu/h	76%	
Gas wall gravity type		
up to 27,000 Btu/h	65%	
over 27,000 up to 46,000 Btu/h	66%	
over 46,000 Btu/h	67%	
Gas floor		
up to 37,000 Btu/h	57%	
over 37,000 Btu/h	58%	
Gas room		
up to 20,000 Btu/h	61%	
over 20,000 up to 27,000 Btu/h	66%	
over 27,000 up to 46,000 Btu/h	67%	
over 46,000 Btu/h	68%	
Gas hearth		
up to 20,000 Btu/h	61%	
over 20,000 up to 27,000 Btu/h	66%	
over 27,000 up to 46,000 Btu/h	67%	
over 46,000 Btu/h	68%	
Pool Heaters	Thermal Efficiency	
Gas fired	82%	4/16/2013

Table 4: Minimum Federal Energy Conservation Standards for Residential Central Air Conditioners, Heat Pumps and Furnaces

Product Class	Efficiency		Effective Date
Residential central air conditioners and heat pumps < 65,000 Btu/h (19 kW)	Seasonal Energy Efficiency Ratio (SEER)	Heating Seasonal Performance Factor (HSPF)	
Split and single package systems	13	7.7	1/23/2006
Through-the wall single package	10.9	7.1	1/23/2006
	12.0	7.4	1/23/2010
Through-the-wall split systems	10.6	7.0	1/23/2006
	12.0	7.4	1/23/2010
Residential furnaces < 225,000 Btu/h (66 kW)	Annual Fuel Utilization Efficiency (AFUE)		
Weatherized gas furnaces	81%		11/19/2015
Non-weatherized gas furnaces	80%		11/19/2015
Mobile Home gas furnaces	80%		11/19/2015
Oil-fired furnace	82%		11/19/2015

Consensus Agreement on Regional Standards for Residential Central Air Conditioners, Heat Pumps and Furnaces

Climate varies enormously in the United States, from frigid Minneapolis to almost tropical Mobile, and from arid Arizona to the humid Southeast. National efficiency standards are important, but regional approaches that increase stringency only where seasonal climate is severe might offer greater savings yet. In 2007, the U.S. Congress enacted the Energy Independence and Security Act (EISA 2007), which provided DOE with the authority to establish regional energy conservation standards for residential central air conditioners, heat pumps and furnaces [10]. Early in 2008, DOE announced its intention to reconsider the final rule on residential furnaces. This action prompted manufacturers represented by the Air Conditioning, Heating and refrigeration Institute (AHRI) and energy efficiency groups represented by the American Council for an Energy-Efficient Economy (ACEEE) to start discussions on a possible agreement regarding federal energy conservation standards for furnaces. These discussions were not successful. However, the official start of the rulemaking on energy conservation standards for residential central air conditioners and heat pumps prompted the different parties to restart discussions in the fall of 2008. However, this time the discussion was expanded to include furnaces as well as central air conditioners and heat pumps. Almost a year later, following very challenging negotiations, compromises by all participants resulted in an overall agreement. The consensus was reached in July 2009 and announced at a public event on October 13, 2009.

The interested parties shared several hopes for the process. First, it was believed that a successful negotiation would allow DOE to proceed to a proposed and final rule more quickly than through the normal, more adversarial procedures. Second, informal discussions allow stakeholders to develop creative approaches, both regulatory and non-regulatory, which are more difficult to develop and discuss in normal notice and comment rulemaking. Third, DOE encouraged stakeholders in the past to consider informal discussions that could result in a consensus agreement. Furthermore, in 2007, Congress amended EPCA to expedite the rulemaking process by authorizing DOE to issue direct final rules establishing new energy conservation standards upon receipt of joint stakeholders' proposals.

The agreement divides the U.S. into three regions: (1) the North, comprising states with population-weighted heating degree days (HDD) equal to or greater than 5,000; (2) the South, comprising states with population-weighted HDD less than 5,000; and the Southwest (see Figure 2). Table 5 depicts the proposed consensus federal minimum energy efficiency standards. In the North, most furnaces will be required to have an efficiency of 90%, vs. 78% today. In the South, central air conditioners will be required to have a minimum SEER of 14, vs. 13 SEER today. Heat pump and oil furnace standards have a national standard. The standards apply to residential single-phase air conditioners and heat pumps less than 65,000 Btu/h (19 kW) of cooling capacity,[2] and single-phase weatherized and non-weatherized forced-air furnaces (including mobile home furnaces) below 225,000 Btu/h (66 kW) heat input. For the first time, a minimum EER for split air conditioners is specified for the states of Arizona, California, Nevada, and New Mexico, making a third region for these products. These are hot dry states where peak performance, as measured with EER, is especially important.

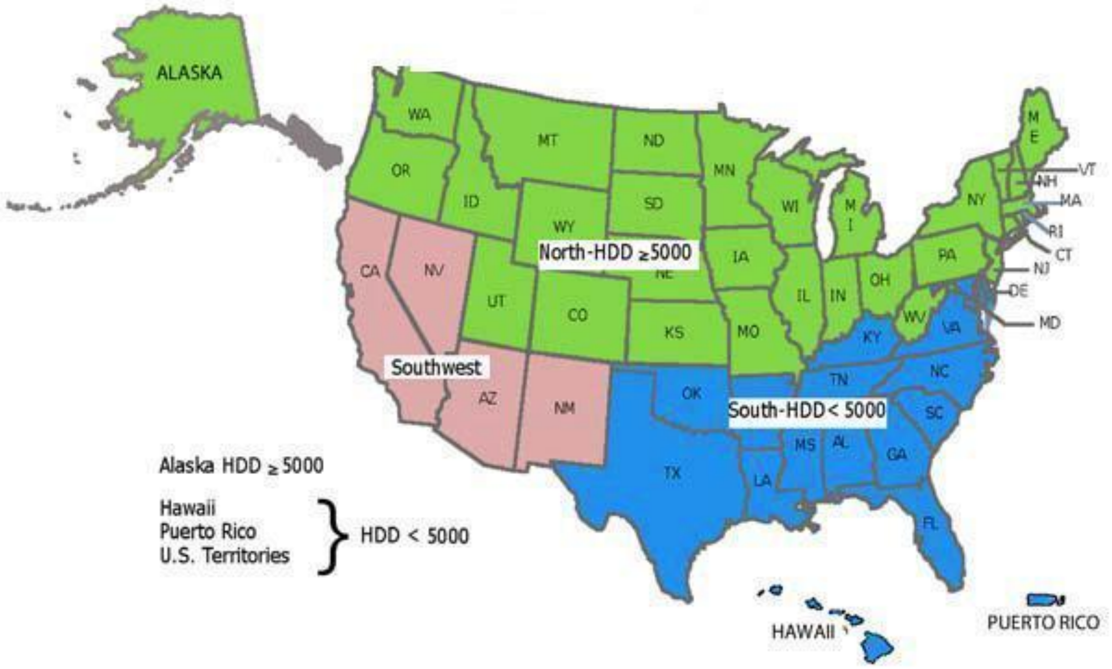


Figure 2: Regional Energy Conservation Standards Map

Table 5: Proposed Minimum Federal Energy Conservation Standards

System Type	≥ 5,000 HDD	< 5,000 HDD	CA/AZ/NM/NV
Split A/C	13 SEER	14 SEER	14 SEER /12.2 EER <45,000 Btu/h 14 SEER /11.7 EER ≥45,000 Btu/h
Split HP	14 SEER /8.2 HSPF	14 SEER /8.2 HSPF	14 SEER /8.2 HSPF
Package A/C	14 SEER	14 SEER	14 SEER/11.0 EER
Package HP	14 SEER/8.0 HSPF	14 SEER/8.0 HSPF	14 SEER/8.0 HSPF
Gas-Pack (weatherized)	14 SEER/81% AFUE	14 SEER/81% AFUE	14 SEER/81% AFUE
Gas Furnaces (non-weatherized)	90% AFUE	80% AFUE	80% AFUE
Oil Furnaces (non-weatherized)	83% AFUE	83% AFUE	83% AFUE

2 Except through-the-wall and small duct high velocity products, which are not included in the agreement.

Note: SEER = seasonal energy efficiency ratio; EER = energy efficiency ratio; HSPF = heating seasonal performance factor; and AFUE = annual fuel utilization efficiency.

The proposed standards will take effect in 2013 for non-weatherized furnaces, two and a half years ahead of the effective date of the 80% AFUE standard published by DOE in 2007 and several years ahead of the new standards that DOE intends to promulgate by May 1, 2011. For central air conditioners, heat pumps, and weatherized furnaces, the standards will take effect in 2015, a year ahead of the planned effective date under the current DOE rulemaking. The agreement also recommends that the effective date for the next DOE rulemaking iteration of the above standards will be January 1, 2019 for non-weatherized furnaces and January 1, 2022 for air conditioners/heat pumps and weatherized furnaces. This schedule represents a substantial acceleration of the next effective dates relative to the dates by which DOE would be statutorily required to complete and implement the next final rule. These accelerated effective dates have the potential to result in considerable additional savings.

The consensus agreement also includes two additional features that increase energy savings. First, the consensus agreement sets new construction/major renovation standards for each region that states may incorporate into their building codes. These are summarized in Table 6. It also would seek amendments to EPCA to allow building codes to provide for building energy budgets and baseline building designs to include covered equipment having an efficiency greater than the federal minimum standard, up to specified levels, as long as at least one option is made available to meet the code through the use of covered equipment at the federally established minimum level. The building code provision alone is expected to save an additional 0.7 quads of primary energy by year 2030.

Second, the agreement calls on DOE, as part of the next rulemakings on central air conditioners and furnaces, to convene meetings of interested stakeholders to develop consensus regarding adding additional energy efficiency metrics for central air conditioners, heat pumps, and furnaces. In the event that consensus is not reached within one year, DOE will have the authority to consider additional efficiency metrics, provided that DOE concludes that the benefits of adding one or multiple metrics substantially exceed the burdens.

Table 6: Energy Efficiency Standards for Building Codes (for New Construction and Significant-Upsizing Only)

System Type	≥ 5,000 HDD	< 5,000 HDD	CA/AZ/NM/NV
A/C	14 SEER	15 SEER	15 SEER/12.5 EER <45,000 Btu/h 15 SEER/12.0 EER ≥45,000 Btu/h
HP	15 SEER/8.5 HSPF	15 SEER/8.5 HSPF	15 SEER/8.5 HSPF
Gas Furnaces	92% AFUE	90% AFUE	92% AFUE
Oil Furnaces (non-weatherized)	85% AFUE	85% AFUE	85% AFUE

These building code provisions require Congressional action and the signatories to the agreement have agreed to jointly advocate these legislative changes.

There are several notable benefits and features of this agreement. By proposing standards for residential furnaces and central air conditioners with respective effective dates of 2013 and 2015, the proposed standards will start saving energy several years ahead of any standards established under the schedule that would apply if DOE adhered to the specific lead times in the statute. In addition, the agreement strikes a balance between the desire for greater state and regional flexibility and the need for a uniform marketplace. Also, manufacturers will have at least three years to prepare for these major changes. A preparation period of this length is particularly important in light of the challenges many of these manufacturers are facing as they are phasing out R-22, the most common refrigerant in residential air conditioners and heat pumps. The levels of the proposed standard have been chosen in order to maintain the diversity of design approaches and engineering flexibility. The proposal is fully consistent with the requirements of EPCA and represents the maximum standards that are technological feasible and economically justified.

The proposed standards are expected to save approximately 3 quads (0.88 x 10^{12} kWh) of primary energy by 2030. These energy savings will result in annual greenhouse gas emission reductions of about 18 million metric tons of carbon dioxide in 2030. Under the agreement, the new standards would raise the minimum efficiency of residential central air conditioning systems in the South by about 8 percent and furnaces in the North by about 13 percent, and would result in a 5 percent reduction of the total heating energy consumption and a 6 percent reduction of the total cooling energy consumption in 2030. The benefits of the proposed standards through energy savings and reduced operating costs over the average estimated life of the covered product exceed the burdens of increase in price to the greatest extent practicable. The new standards are projected to save U.S. consumers about $13 billion in today's dollars between 2013, when the new standards begin to take effect, and 2030 — taking into account the incremental cost of the more efficient equipment. The consensus agreement was submitted to both the U.S. Congress and DOE. A proposed legislation adopting the consensus agreement and several other energy efficiency provisions was introduced in the Senate in February 2011. At the same time the Department of Energy is expected to issue a notice of proposed rule (NOPR) adopting the agreement. While the final outcome of both legislative and regulatory efforts is not certain, it is expected that the agreement will be adopted as it represents a consensus among major stakeholders.

Federal Energy Efficiency Tax Credits

Tax credits have recently been used to accelerate the market penetration of very high efficient products. The U.S. Congress enacted legislation with such provisions three times in the past five years, first in 2005 [11], then in 2009 [12], and more recently in 2010 [13].

The latest tax credits are significantly lower than in previous years and reflects current efforts in the U.S. Congress to try to balance the growing budget deficit with the need to stimulate the economy. The new tax credits can be claimed for high efficiency products placed in service between January and December 2011. Table 7 summarizes the tax credit provisions for residential air conditioners/heat pump, furnaces and water heaters.

Table 7: Federal Energy Efficiency Tax Credits for Residential Central Air Conditioners/Heat Pumps, Furnaces and Water Heaters

Equipment Type	Minimum Energy Efficiency	Tax Credit ($)	Effective Date
Central air conditioners Split system Package system	 ≥16 SEER, 13 EER ≥14 SEER, 12 EER	 $300	1/1/2011 to 12/31/2011
Central air source heat pumps Split system Package system	 ≥15 SEER, 12.5 EER, 8.5 HSPF ≥14 SEER, 12 EER, 8 HSPF	 $300	
Furnaces Gas Oil Propane Gas hot water boiler	 ≥95% AFUE ≥95% AFUE ≥95% AFUE ≥95% AFUE	 $150	
Advanced main air circulating fan	≤ 2% of furnace total energy use	$50	
Water heaters Gas/oil/propane	 ≥ 0.82 Energy Factor or ≥ 0.90 Thermal Efficiency	$300	

Heat pump	≥ 2.0 Energy Factor		

Conclusions

Federal energy efficiency standards for residential consumer products, including heating, cooling and water heating equipment have saved an estimated 2.7 quads (0.79 x 10^{12} kWh) of primary energy since the enactment of NAECA in 1987. During the past two years, DOE issued or codified new efficiency standards for more than twenty different products. These new standards are expected to save consumers between $250 and $300 billion on their energy bills through 2030. However, the current federal rulemaking process is showing signs of weakness and has been challenged in courts several times in the past few years. In a profound departure from past practice in which an adversarial DOE process yielded unpredictable efficiency standards that did not satisfy participants on any side, manufacturers, state agencies, and environmental advocates succeeded in reaching a consensus on a suite of measures to improve the delivered efficiency of residential furnaces, air conditioners, and heat pumps. It is hoped that the advantages to all parties, including consumers, will commend this model for consideration in establishing future energy conservation standards for other products.

References

[1] U.S. Department of Energy, *2008 Buildings Energy Data Book*, Washington, D.C., 2008.

[2] Neubauer, Max, Andrew deLaski, Marianne DiMascio, and Steven Nadel. 2009. *Ka-BOOM! The Power of Appliance Standards: Opportunities for New Federal Appliance and Equipment Standards.* ACEEE Report A091. Washington, D.C.: American Council for an Energy-Efficient Economy.

[3] U.S. Department of Energy, *Multi-Year Program Plan – Building Regulatory Programs,* Washington DC, October 2010.

[4] U.S. Congress, *National Appliance Energy Conservation Act, Public Law 100-12,* U.S. Government Printing Office, Washington D.C., 1987.

[5] American Society of Heating Refrigerating, and Air Conditioning Engineers, Standard 90, *Energy Conservation In New Building Design,* ASHRAE, Atlanta, GA, 1975.

[6] U.S. District Court, *Consent Decree. Consolidated Civil Actions No. 05 Civ 7807 (JES) and No. 05 Civ. 7808 (JES),* Southern District of New York, April 6, 2006.

[7] U.S. Congress, *Department of Interior and Related Agencies Appropriations Act for Fiscal Year 1996, Public Law 104-134,* U.S. Government Printing Office, Washington D.C., 1996.

[8] U.S. Department of Energy, *Federal Register, Vol.66, No.11*, p.4474-4494, January 17, 2001.

[9] U.S. Department of Energy, *Federal Register, Vol.75, No.73*, p.20112-20236, April 16, 2010.

[10] U.S. Congress, *Energy Independence and Security Act of 2007, Public Law 140-110,* U.S. Government Printing Office, Washington D.C., 2007.

[11] U.S. Congress, *Energy Policy Act of 2005, Public Law 109-58,* U.S. Government Printing Office, Washington D.C., 2005.

[12] U.S. Congress, *American Recovery and Reinvestment Act of 2009, Public Law 111-5,* U.S. Government Printing Office, Washington D.C., 2009.

[13] U.S. Congress, *Tax Relief, Unemployment Insurance, and Job Creation Act of 2010, Public Law 111-312,* U.S. Government Printing Office, Washington D.C., 2010

Market Trends on the Air Conditioners Market and their Impact on Energy Consumption

Enzo Frasio

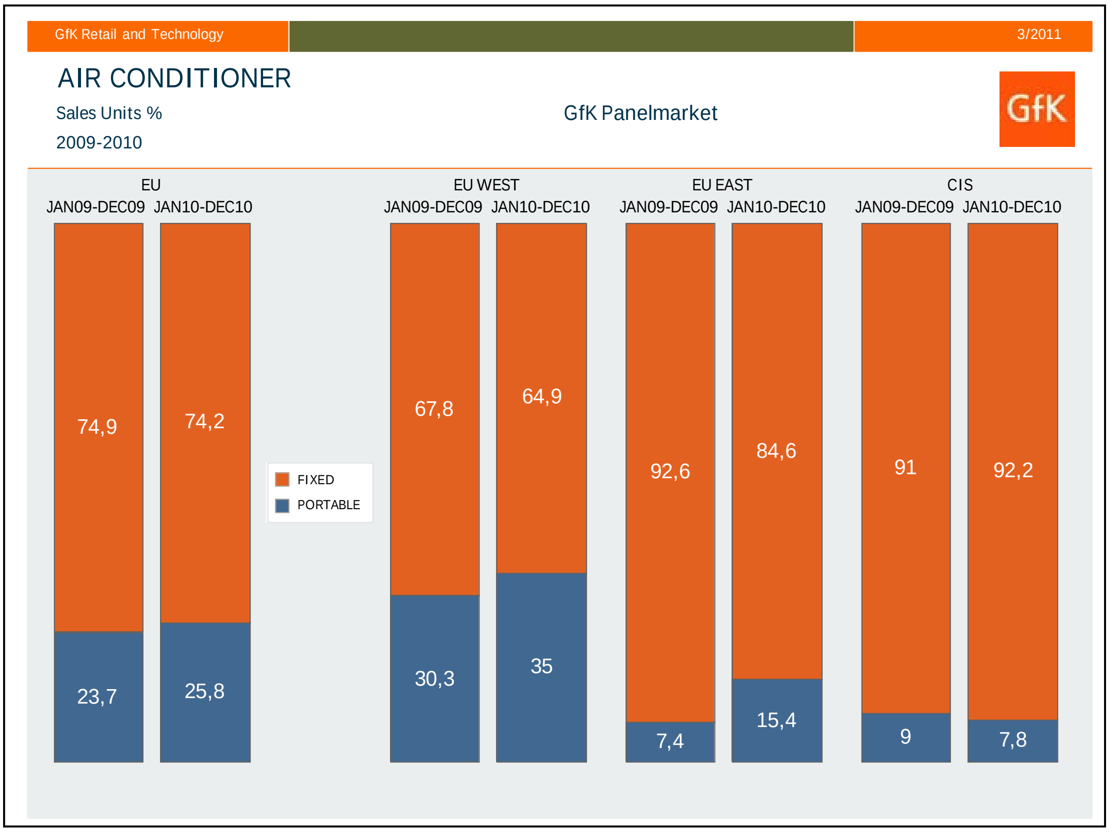
Group Account Manager – GfK Retail and Technology

1- MARKET TRENDS

During the last years Air Conditioners residential market has grown fast on a worldwide prospective.

In Europe in the last two past years market was negative, mainly due to the particular weather conditions. Only during 2010 the Air Conditioners European market recovered: +23% (Jan-Dec 2010 vs Jan-Dec 2009), this trend was mainly due to a warmer summer period in whole Europe, predominantly due to July hot weather conditions.

This market, and its development, is strongly related to seasonality. Summer period for most of the regions of the world represents more than 80% of the total yearly volume.



Slide *1: Type of Air Conditioner across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)*

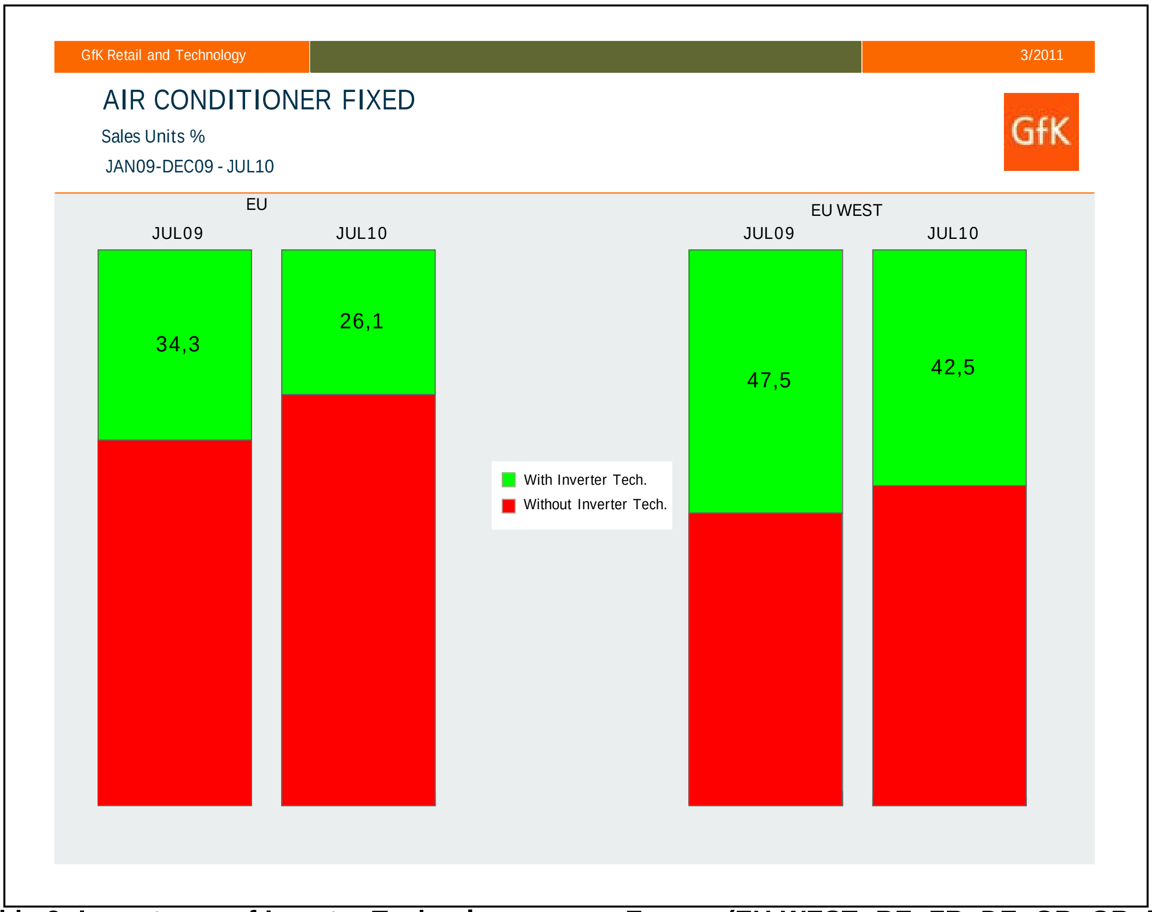
During 2008 and 2009 summer period in Europe was short and not so warm and the direct consequence was at the end of the year GfK audited a negative market in terms of Air Conditioner sales. This development is also related to the fact that people buys an Air Conditioner appliances as an “impulse buying”.

Indeed, during these years portable’s sales considerably grow up during high season (no installation costs are needed). For some type of conditioners (e.g. Multi - Split) installation may be fairly difficult so became quite unfeasible to install high end equipment during seasonal peaks. (see slide # 1)

This is a result related to two main reasons: typical human behaviour (the weather is warm → I need an Air Conditioners), and manufactures/retailers “low” capacity/possibility to make pressure on customers purchasing, pushing seasonal variations.

The impulse buying during hot months combined with strong price user attention push the market towards high energy consuming models and “lower” technologies (characterized by low energy efficiency and no inverter products).

Consequentially during the extremely “hot” 2010 July we had registered a big drop of inverter technology importance. (see slide # 2)



Slide 2: Importance of Inverter Technology across Europe (EU WEST: BE, FR, DE, GB, GR, IT, NL, PT, ES, SE)

This is not true for those regions across the world where the climate conditions are more stable, where the average temperatures are higher, and where the humidity and the air are not so "clean and pure": due to the pollution and to the geographical location. For those regions, for example Middle East and Asia, Air Con represents an extremely positive and huge market, year by year.

2 - ENERGY CONSUMPTION: THE IMPORTANCE OF NEW TECHNOLOGICAL FEATURES

Considering the energy consumption topic, Air Conditioners market shows a pretty different approach compared to Major Domestic appliances as Refrigerators and Washing Machines.

We have seen, analyzing Major Domestic appliances market, that issues as low energy consumption and energy labelling are very important and that market is going on an advanced stage concerning the energy saving topic.

Slide 3 ***Energy Efficiency Classes across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)***

If we compare Air Con to Refrigerators, the trends of “A energy efficiency class” market shares are similar (very positive in most of the regions); but they don’t represent such a huge market share in Europe as a whole. And we have to consider that probably Air Conditioners are one of the most energy-consuming appliances within the domestic appliances market. (see slide # 3)

If we focused on new launched models (see table # 1), it’s possible to see how the importance of high energy efficiency classes is increasing in last four years.

In west Europe where the high efficiency are almost the totality of the market, the “A Class” share has shown big increase reaching the 74% of share during 2010.

IMPORTANCE OF "A" ENERGY EFFICIENCY CLASS WITHIN EACH YEAR.
(THE PERCENTAGE IS CALCULATED ON THE MODELS LOUNCHED IN EACH SINGLE YEAR)

YEAR	TOTAL EUROPE	WEST EUROPE	EAST EUROPE	CIS
2007	**41%**	49%	35%	23%
2008	**51%**	60%	58%	28%
2009	**52%**	68%	46%	20%
2010	**57%**	74%	63%	26%

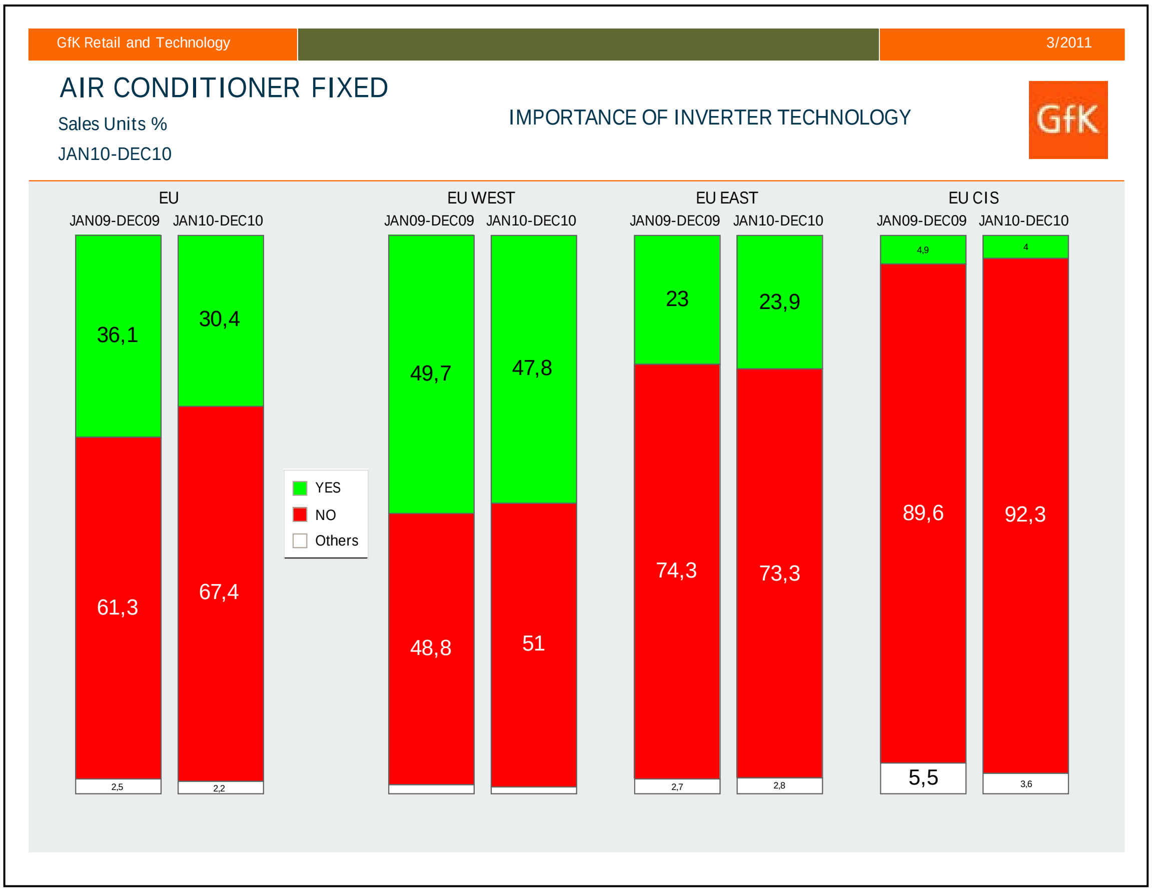
Table 1

The same phenomenon is true also within East Europe and CIS, considering as already mentioned, in the previous chart (see slide # 3) the different energy mix by macro area.

New technological features as Inverter or Heat Pump are characterizing Air Con market, showing very positive trends. These two high end features allow to reduce energy consumption and consequentially environmental impact.

Analyzing Europe as a whole, Inverter represents more than 30% of the whole residential Air Conditioners market. If we go deeply into figures we find out that trends and importance of Inverter technology are pretty different: for Western Europe it represents nearly 50% of the total volumes, while the On-Off model sales are decreasing faster.

Concerning Central/Eastern Europe things are really different: both in terms of market share and development. (see slide # 4)



Slide 3 ***Importance of Inverter Technology across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)***

This different result across Europe is manly related to the different energy cost that there is in Europe from West to East and a consequent different "green" consumer behaviour.

3 – INDOOR AIR QUALITY

“Air quality” issue, referring to indoor places like houses, offices, public places, is becoming more and more important concerning ecological and environmental comfort.

Indoor pollution would be potentially more dangerous than outdoor pollution so it is becoming a caution note for every responsible individual and family person. It is plausible to foresee that in the next years the indoor air quality would become important for every household with a strong growing appealing for companies’ attention.

There are mainly two reasons to explain the growing importance of the quality indoor air: the first reason, related do consumer habits, deals with the increase of time that people spend in indoor places who combine with the increasing of individuals suffering from allergies and asthma generate a big impact boosting the end user demand.

The second concerning the improvement in reductions of air change between indoor and outdoor places due to better house thermal insulation. This last reason causes an increase in recycling of air and consequently the air quality gets worse.

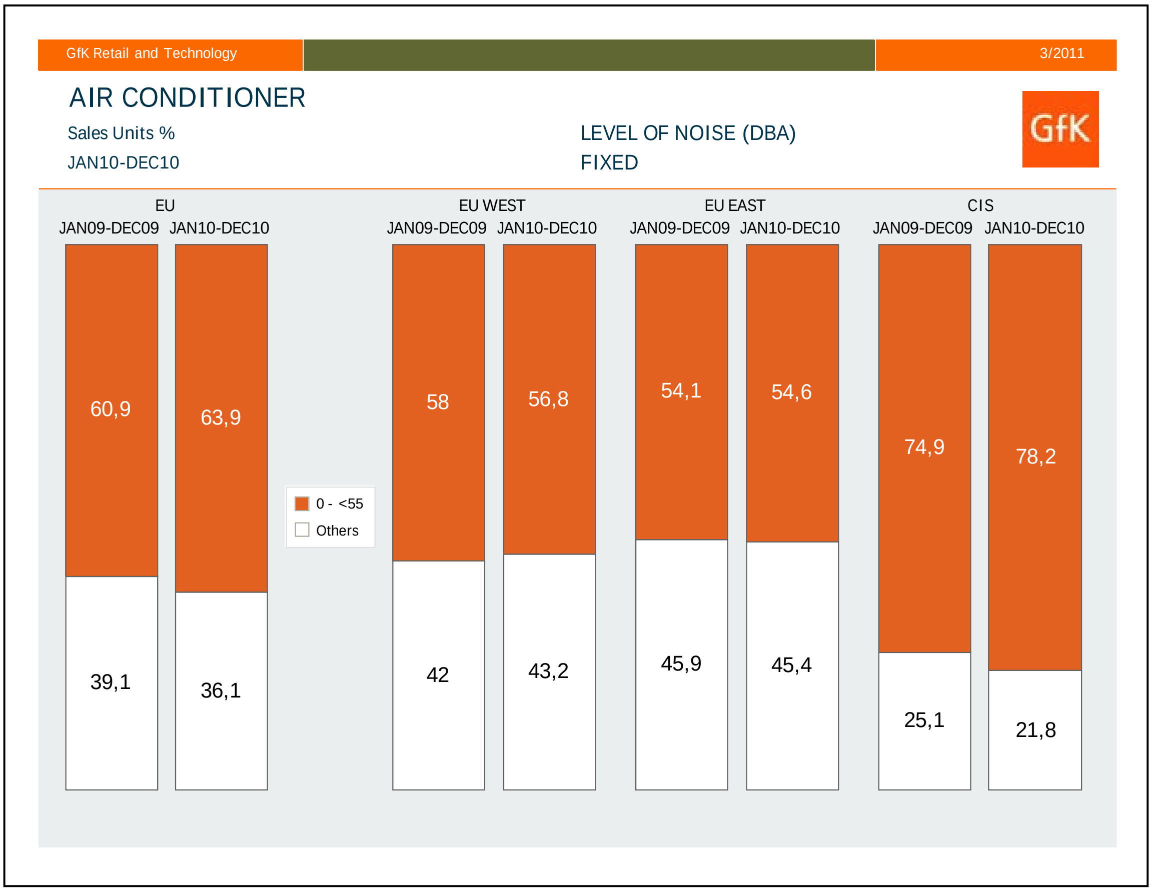
It’s easy to understand why the topic of cleaning up indoor air become important.

4 - FUTURE DEVELOPMENTS

Air Conditioning market is growing, energy-saving and environmental protection will become the main theme.

We can find an example in the kind of refrigerant gas used in “new” air conditioners and in the reduction of noise pollution.

In the last generation of air conditioners ecological and environmentally refrigerant gas are used, like methane and LPG, reducing the CO_2 emissions; also the sound emissions has been lowered until 50 dbA ca for outdoor units, and 20 dbA for indoor units. (see slide # 5)



Slide 5 ***Level of Noise (calculated in DBA) across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)***

The companies' R&D department are working to find new ecological materials that are able to replace currently employed materials.

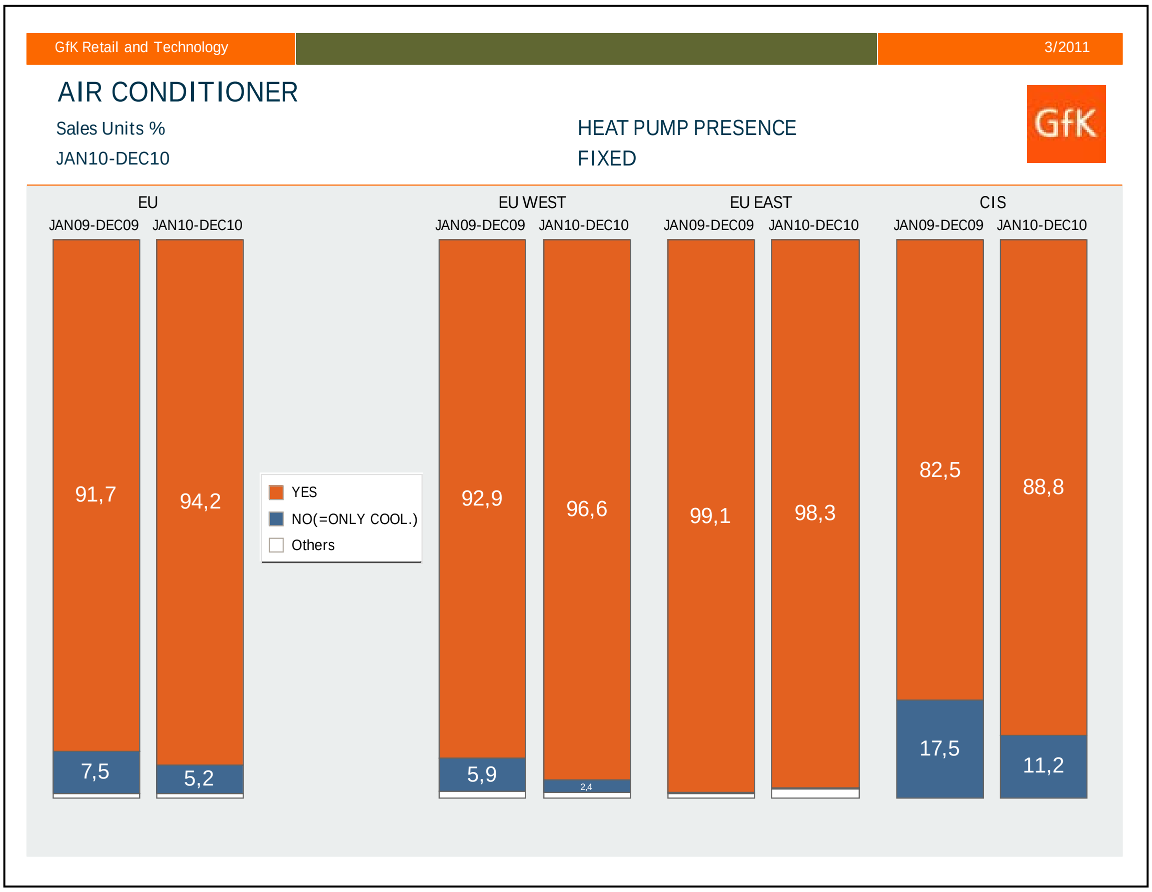
Air conditioning companies are also trying to implement guidelines for consumers to "teach" them the best way to use their air conditioners, main focus on a correct installation and also on a good maintenance of the system for example frequently cleaning of the "air filters".

Another new way to reduce CO_2 emission is reached using combine photovoltaic panels system and air conditioners units out coming with a lower energy consumption. It is easily comprehensible the potential great energy savings that these new devices can generate.

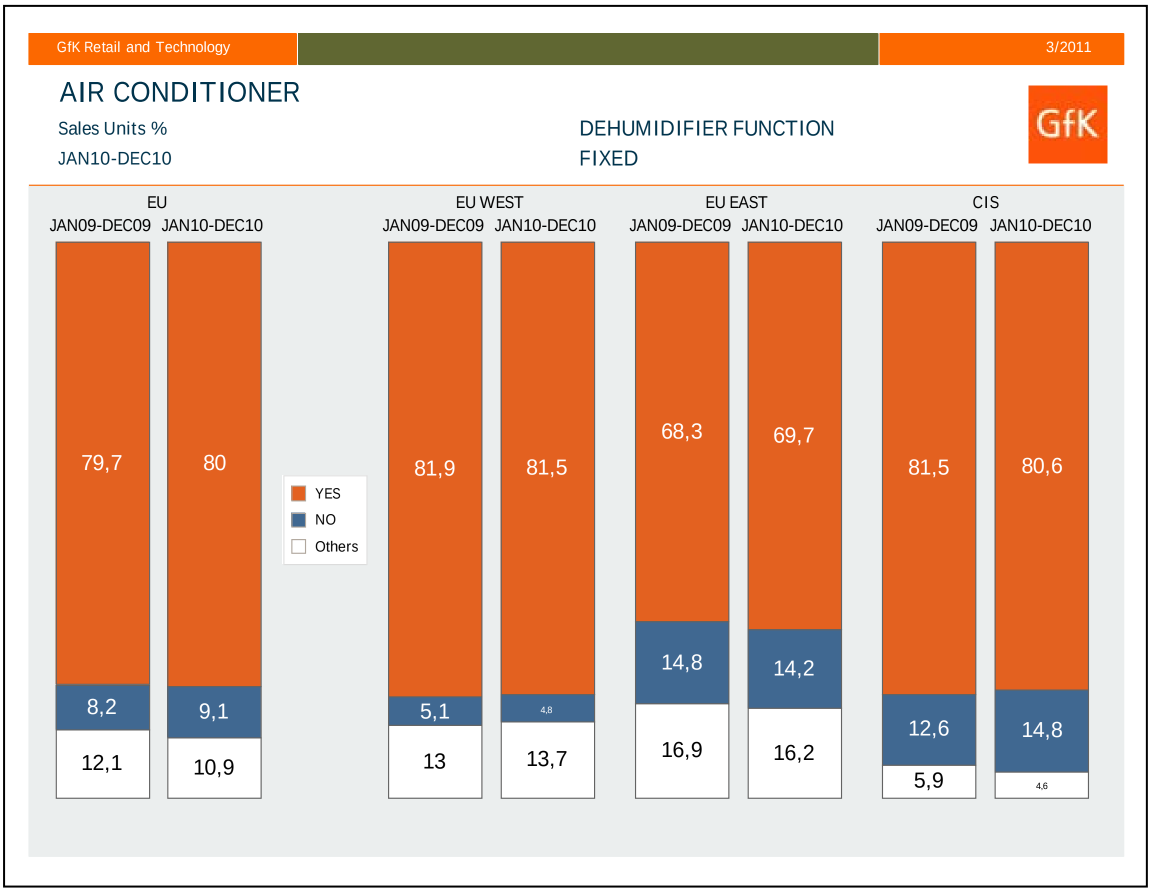
Within the next years high energy efficiency classes and inverter technology will forced to become reality not only for some country, but all over the world.

One of the most important growing topic is "multi-functionality" of the appliances that will be a key market driver in a midterm length: not only cooling but also heating, cleaning and dehumidifying.

Referring to west EU almost the totality of the ac systems adopted the Heat pump technology (see slide # 6), while the dehumidifier feature is installed in the 80% of the machines showing a strong increase (see slide # 7).



Slide 6 ***Heat Pump presence across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)***



Slide 7 Presence of *Dehumidifier function across Europe (EU: BE, BG, HR, CZ, FR, DE, GB, GR, IT, NL, PL, PT, RO, SK, SL, ES, SE. CIS: RU, UA, KZ)*

We are in front of a big convergence that had characterized other sectors (e.g. Consumer Electronics or Information Technology) during the past; we can do a comparison between the "digital convergence" finding out some differences an analogies, definitively the speed of "House Climate convergence" is completely different compare to the digital one but it is reasonable to think on an accelerating of the phenomenon during a short term period.

In no doubt analogy is that in an unexpected way technology makes a fusion of completely different technologies an example of these is the combination with a "design" hood and air conditioning system ended by two Italian manufacture from one side Faber technology that ensures the hood, and on the other side Olimpia Splendid technology ensures the air conditioner with Heat pump. (see figure # 1)

Figure 1 Kilma model

This revolutionary high-end hybrid product called Klima could be considered as a sum up of this trend. In fact it combines four different function: Hoods, Air Conditioning, Purifier and Heating technology; if it is still a “niche product” is a great support of idea that having only one appliance able to cool, warm, clean and purify our houses, with a low ecological impact and characterized by a huge energy saving, will become undoubtedly a must.

Energy efficient room air conditioners – best available technology (BAT)

Anette Michel, Eric Bush, Jürg Nipkow, Conrad U. Brunner, Hu Bo

Topten International Services

Abstract

More than 5 million room air conditioners (ACs) are sold per year in Europe, 35 million in China. Most air conditioners combine heating and cooling, and sales are expected to grow further. Total annual electricity consumption by air conditioners in Europe is estimated at more than 40 TWh, in China at 200 TWh. The most efficient ACs are split models with a variable frequency drive (VFD). Market shares of variable speed ACs are on the rise both in Europe and in China. They are more efficient at part load conditions than fixed speed (on/off) appliances and can keep the requested room temperature more constant. In China, the efficiency indicator for variable speed ACs (SEER / HSPF) does include part load conditions, while in Europe a part load measurement standard is actually in preparation. The implementation of seasonal efficiency indicators, strict minimum efficiency requirements and an effective energy label is key for the promotion of high efficiency air conditioners. In China, the implementation of MEPS and an energy label for variable speed air conditioners triggered a significant increase in market share and efficiency. A Chinese high efficiency AC was tested according to four different measurement standards (European current and future, Chinese and US). Results show that the best available technology (BAT) on the European market is comparable to the one in China. Very high SEER results according to the future European standard raise the expectation that several ACs will already reach the A+++ classes of the new energy label.

Introduction

Room air conditioners transport heat from inside a room with a refrigerant cycle to the outside. Most air conditioners consist of a reversible heat pump and can also be used for room heating instead of cooling. The most important components of an air conditioner are evaporator and condenser with fans plus a compressor.

Four main room air conditioner construction types can be found on the market:

- Split air conditioners consist of an indoor- and an outdoor-unit, which are fixedly installed and linked together with the refrigerant line. The condenser and the compressor are located in the outdoor unit, not delivering any waste heat indoors. Several indoor units can be connected to one outdoor unit – resulting in a multi-split air conditioner. Mobile split air conditioners have a portable indoor unit containing the compressor, which leads to less efficiency.
- Single ducts consist of one single unit placed freely in the room. The air is expelled through a duct, which requires a window to be open. Warm air is drawn into the room, as the condenser is cooled with air taken from the room – the cooling effect is small and only local.
- Double ducts also consist of one single unit, but have separate ducts for air intake and exhaust. Either double ducts are moveable and placed next to a window, or the ducts are mounted through the wall.
- Through-the-window air conditioners (also: compact or through-the-wall AC) are widespread in the USA, but of no importance in Europe. They are too compact to be efficient and require an opening in the insulation.

The efficiency of split air conditioners on American, Asian, Australian and EU markets has improved by 3% per year in the past 15 years, while the EER of the three latter (unitary or compact) types has virtually remained the same [1]. Split air conditioners are not only by far the most efficient, but also the most popular type in Europe as well as in China. Therefore the focus of this paper is on split air conditioners. The most energy efficient split air conditioners have a variable frequency drive (VFD) and a permanent-magnet motor. The VFD allows the air conditioner's compressor to run at part load and adapt its workload to the temperature change needed. Fixed speed air conditioners on the other hand reach a certain temperature by switching from full load operation to off, which is not very efficient.

The current EU energy label for air conditioners refers to the Energy Efficiency Ratio (EER, cooling function) and Coefficient Of Performance (COP, heating function) to indicate the energy efficiency of air conditioners. These indicators are measured at full load operation and do not account for the efficiency gains by the variable speed drives' ability to work at part load. Seasonal efficiency indicators (SEER for cooling, SCOP or Heating Seasonal Performance Factor (HSPF) for heating) do consider the different cooling or heating needs during the year and include part load operation of air conditioners. Many non-EU countries have been applying seasonal efficiency indicators, while the EU is about to introduce them now.

Air conditioner markets in Europe and China: trends, best available technology (BAT) and energy consumption

Europe

Market trends

Annual air conditioner sales in the EU are expected to grow from 4.9 million units in 2005 to almost 10 million by 2020. At the same time the stock will increase from around 40 million units to 110 million installed air conditioners [2].

National markets across the EU differ strongly due to different climate, building design, legislation and income. In Southern countries for instance heating with air conditioners is common, while houses in Northern countries usually have central heating installed. Across Europe, about 75% of the sold air conditioners include a reversible heat pump capable of cooling and heating. Variable speed (inverter) air conditioners have also become popular: in 2007 55%-75% of the sales were air conditioners with a variable speed drive. Sales shares of both reversible heat pumps and variable speed air conditioners are expected to grow further, while split cooling only appliances (without heating function) are expected to disappear from the market. Single ducts and double ducts, today accounting for about 15% of the sales, are expected to become more popular however [2].

Sales data from 5 European countries from 2005 - 2008 (till October) show that class A air conditioners by now account for most of the sales (Fig. 1).

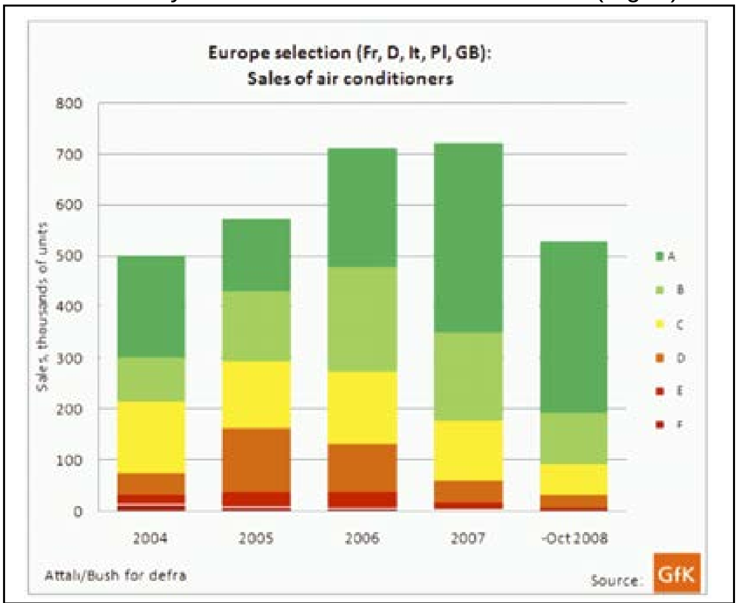


Figure 1: Air conditioner sales in 5 EU-countries (France, Germany, Italy, Poland, Great Britain) 2004 – October 2008. Source: GfK data in [3].

This market evolution seems to have been triggered mainly by the introduction of the energy label for air conditioners in 2002 [4]. By now high efficiency air conditioners reach Energy Efficiency Ratio (EER) values of up to 5.63 [5] - way beyond the class A threshold of 3.2.

Energy efficiency: Best available technology (BAT) and average air conditioners

Split air conditioners with a variable speed drive and a permanent-magnet motor are the most energy efficient air conditioners. For the heating mode, some products switch to electrical resistance heating, a highly inefficient way of heating. Potentially efficient are products with a reversible heat pump instead. Energy efficiency of air conditioners has been indicated by the EER (Energy Efficiency Ratio) for the cooling mode, and, if present, by the COP (Coefficient of Performance) for the heating mode. These indicators give the ratio of the total cooling or heating output and the energy consumption.

Topten.eu, an independent database for the most energy efficient products on the European market [6] [7], lists six air conditioning models of four different brands with an EER ≥ 5 as the European BAT for split air conditioners with a cooling capacity of 4kW or less, the most efficient reaching an EER of 5.63. For higher capacity air conditioners, Topten identifies three models with an EER > 4.1 as the BAT, while the four most efficient multi-split models reach values above 3.5. The COP values of most of these models are slightly higher than the EER values (BAT EER and COP values see Tab. 1). Inefficient products on the market have EER of around 2 and COP around 2.4. Resistance heating results in a COP of 1.

Table 1: EER (cooling) and COP (heating) of best available products on the European market

Air conditioner type	EER: BAT in EU	COP: BAT in EU
Split < 4kW, variable speed	5.63	5.68
Multi split, variable speed	4.97	4.65
Split > 4kW, variable speed	4.52	4.52
Mobile split	3.22	3.67

Data source: www.topten.eu

The total energy consumption depends mainly on the outdoor climate, building type and age, the capacity and the type of the appliance and can vary strongly. An efficient split air conditioner with an EER of 5.63 and a COP of 5.68 consumes around 800 kWh per year[1]. According to [4] the average EER of the air conditioner models sold in the EU-27 in 2008 was around 3.23, the average COP around 3.4. Such an average air conditioner consumes almost 90% more electricity than a BAT model – around 1500 kWh per year (Fig. 2).

[1] Assumed are 350 hours of operation in cooling, 1400 in heating mode, which is in line with the ecodesign working documents. Standby consumption includes thermostat off and crankcase heating. For average products standby consumption is assumed to account for 17%, for efficient products for 7% of the total consumption. All electricity consumption indications are for air conditioners with a cooling capacity of 2kW and a heating capacity of 2.5 kW.

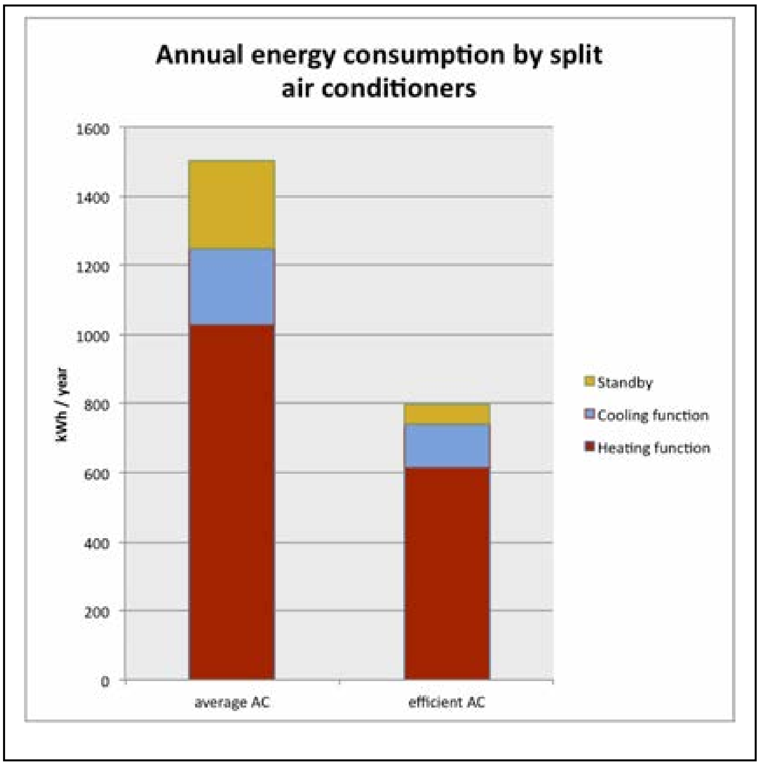


Figure 2: Annual energy consumption by split reversible air conditioners[1]**.** Data source: [5], [4] and [2].

Increasing total consumption

Total annual electricity consumption by air conditioners in Europe is estimated at 30 TWh in 2005 [8], in 2010 it will have reached more than 40 TWh. Two thirds of the total consumption are attributed to the heating function [2]. By 2020 electricity consumption will increase to around 75 TWh annually without any measures (business as usual) [8], mainly due to higher market penetration [2]. The expected increase of 30 TWh annually corresponds to the production of close to five 750 MW-power plants.

The planned EU policy measures (minimum requirements and energy label) are expected to lead to savings of around 11 TWh annually by 2020 [8] – only one third of the expected increase in electricity consumption. The saving potential is higher than that: assuming that today's entire stock was replaced by BAT appliances would lead to annual electricity savings of more than 12 TWh. The expected future stock of 110 million units in 2020 [2] holds a saving potential of around 31 TWh per year.

China

Market trends

China is the largest air conditioner manufacturing country of the world. 81 million air conditioners have been produced in China in 2009. Due to the urbanization process and the fast economical development the Chinese domestic air conditioner market started to boom increasingly after the year 2000 till today. In 2009, sales reached 35 million annually [9]. They are expected to keep increasing in the next few years. The Chinese government has implemented a series of policy incentives: an 'old to new' program, a high efficient air conditioner subsidy program and a 'home appliances going to the rural market' program. These programs additionally stimulate the sales and contribute to the dissemination of air conditioners.

The Chinese market is dominated by split air conditioners. The sales share of wall split air conditioners keeps increasing since 2006. In 2010, sales share of wall split air conditioners reached 85% [10]. Topten China found that the cooling capacity of 5000W can be recognized as the line to distinguish the wall and free standing air conditioners. Free standing air conditioners have higher cooling capacities, while however they are less efficient than wall models.

Figures 3 and 4: Split air conditioners, indoor units: wall and free standing type

Although China is a huge country combining different climates and building types, 87% of all air conditioner models on the market include a heating function (more than 62% with a heat pump, 25% function with electrical resistance heating) [11]. Cooling only air conditioners only account for a small portion of market share in tropical areas. Variable speed air conditioners have become more and more popular in the last two years. They have obvious advantages regarding comfort and energy efficiency. The market share of variable speed air conditioners has increased from 2% in 2006 to more than 20% in 2010 (24.45% in wall split and 20.57% in free standing ACs) [10]. This significant market evolution mainly happened in 2009. It was triggered by the implementation of the minimum efficiency requirements [11] and the labeling program for variable speed air conditioners [13], which caused the big manufacturers to invest more in promoting variable speed air conditioners. The Chinese government dedicates to investing in the research and development of converter and variable frequency drive (VFD) techniques. The latest “national promotion categories of energy conservation techniques” [14] listed the converter and VFD techniques as high priority. The market share of variable speed air conditioners is expected to grow to 50% in the next 5 years [9]. Most fixed speed air conditioners on the Chinese market still use R22 as refrigerant, which is being phased out in Europe due to its ozone depletion potential since 2000. The non-ozone-depleting R410A, which is the dominating refrigerant in Europe, is also most common in Chinese variable speed air conditioners.

Increasing energy efficiency and total energy consumption

The average energy efficiency of air conditioners has improved in recent years. Tables 2 and 3 show the average efficiency improvement from 2008 to 2009 [9]. Different measurement and calculation methods are applied for fixed speed and variable speed air conditioners: the efficiency of fixed speed air conditioners is indicated as EER (Energy Efficiency Ratio (full load)), while the efficiency of variable speed air conditioners is indicated by the SEER (Seasonal Energy Efficiency Ratio, part load included).

Table 2: Fixed speed air conditioners: average EER improvement from 2008 to 2009

Cooling capacity (kW)	Average EER in 2008	Average EER in 2009	Improvement rate (%)
CC ≤ 4.5	3.04	3.30	8.6
4.5 < CC ≤ 7.1	2.84	3.17	11.6
7.1 < CC ≤ 14	2.75	3.06	11.3

Data source: [9]

Table 3: Variable speed air conditioners: average SEER improvement from 2008 to 2009

Cooling capacity (kW)	Average SEER in 2008	Average SEER in 2009	Improvement rate (%)
CC ≤ 4.5	4	4.64	16.0
4.5 <CC ≤ 7.1	3.62	4.21	16.3
7.1 <CC ≤ 14	3.62	3.86	6.7

Data source: [9]

Along with Topten Europe, Topten China [15] [7] selects and presents the most energy efficient air conditioners from 1200 models sold on the Chinese market. The efficiency levels of the BAT identified by Topten China are listed in tables 4 and 5.

Table 4: EER (cooling) of Best available fixed speed air conditioners on the Chinese market

Air conditioner type	EER: BAT in China
Split < 2.8kW, fixed speed	4.11
2.8kW ≤ Split ≤ 4.5kW, fixed speed	5.00
4.5kW < Split ≤ 6.0kW, fixed speed	3.65
6.0kW < Split ≤ 7.5kW, fixed speed	3.51

Data source: [15]

Tab. 5: SEER (cooling) of Best available variable speed air conditioners on the Chinese market

Air conditioner type	SEER: BAT in China
Split < 2.8kW, variable speed	7.33
2.8kW ≤ Split ≤ 4.5kW, variable speed	6.2
4.5kW < Split ≤ 6.0kW, variable speed	5.39
6.0kW < Split ≤ 7.5kW, variable speed	5.00

Data source: [15]

Because of the increasing stock and prolonged using times, air conditioners have become one of the biggest electricity consumers in Chinese residential energy consumption. According to the analysis and estimation of the China National Institute of Standardization, more than 200 TWh were consumed by air conditioners in 2009 [9]. According to the reference scenario (enhancing the energy efficiency standards in the normal process), 22.4 TWh can be saved in 2020; while according to the BPN scenario (including a revision of the MEPS leading to all products on the market reaching the highest efficiency grade), even 33.3 TWh can be saved in 2020 [9].

Policy measures in Europe and China: energy label, MEPS and measurement standards

Europe

Energy label: revision

The current energy labels for air conditioners were introduced in 2002, and are accordingly outdated: the class A limit is at 3.2, while BAT split air conditioners reach EER values of 5.63.

The energy label is currently being revised. The latest Commission Working Document (WD) from November 2010 [16] suggests maintaining three different energy label scales for double ducts, single ducts and all other air conditioners with a rated cooling capacity of up to 12 kW. Seasonal efficiency indicators are not applied for double ducts and single ducts, but effectively for split air conditioners only. The most efficient split air conditioners are expected to already reach the super-A classes A+ to A+++ of this labeling scale. On the other hand, the proposed minimum efficiency requirements (see below) will lead to most lower classes being empty after 2014 [17].

New minimum efficiency requirements

Ecodesign requirements are currently being discussed based on a Commission Working Document from November 2010 [18]. The WD proposes different minimum efficiency requirements for (split) room air conditioners, single- and double-ducts, maximum power input for standby and off mode and maximum sound power levels. According to the proposal, starting from 2012 air conditioners will have to meet at least class D cooling and class B heating efficiency, from 2014 class C cooling and class A heating efficiency. For appliances using refrigerants with a Global Warming Potential (GWP) below 150, such as Hydrofluoro-Olefines (HFO), propane or CO_2, a 10% reduction of the required efficiency levels is proposed. The member states will vote in February / March 2011.

Measurement standard

The current measurement standard EN14511 [19] is being revised and amended with EN 14825 [20] to include a method to measure and calculate seasonal performance indicators based on part load condition measurement. These seasonal performance indicators are the basis for the Ecodesign requirements as well as for the revised energy label. The current and the draft revised measurement standard have been compared in a test of a Chinese air conditioner by Topten International Services. The results are presented and discussed below.

China

Measurement standards: 2 in parallel

China has developed two parallel measurement standards for air conditioners, using different energy efficiency indicators: for fixed speed air conditioners, EER (full load) is applied, while for variable speed air conditioners, SEER (including part load conditions) is applied.

Minimum energy performance standards (MEPS)

The first MEPS for fixed speed air conditioners was implemented in 1989 (GB12021.3). This standard was revised in 2000, 2004 and the latest version was implemented in 2010 [21]. Compared to the version from 2004, the minimum requirement has been increased significantly by an EER of 0.6 (to an EER of 3.2 for ACs with a cooling capacity < 2800W), which means the former grade 2 limit of the energy label was set as minimum efficiency requirement in the new standard (the lower the grade, the better the efficiency).

After almost 20 years of policy measure implementation for fixed speed air conditioners, the first MEPS for variable speed air conditioners was implemented in 2008 (GB21455). This standard mainly triggered the market expansion of variable speed air conditioners. The market share increased from below 10% before 2008 to more than 20% in 2010.

The average energy efficiency of fixed speed and variable speed air conditioners improved significantly. According to a conformity test conducted by Topten in 2010, all 9 tested air conditioners did meet the requirements of the self-declared label grades, even though the measured EER was lower than indicated for all tested models but one. Manufacturers profit of the large measurement tolerance of up to 15% for the EER declaration, which sums up from a 10% tolerance for the cooling capacity measurement and a tolerance of 5% for the power input measurement [22].

China Energy Labeling program

The Energy Labeling program was introduced in China in 2005. Fixed speed air conditioners were the first product group the meaningful label was implemented for. The label discloses the most important energy information of the air conditioner to the consumers. With the latest revision of the measurement standard and the labeling regulation the number of grades has been reduced from 5 to 3 [23]. The energy label for variable speed air conditioners was implemented in 2009. Both the fixed speed and variable speed air conditioner labels show the efficiency of the cooling function only.

SEER: 2 different calculations

According to the measurement standards, the SEER of variable speed air conditioners is calculated based on the testing of 100% and 50% of the rated cooling capacity. The definition of the cooling season plays an essential role in the calculation of the SEER. The testing standard (GB/T 7725-2004 [22]) defines the cooling season with a using time of 2399 hours, while the energy efficiency standard (GB 21455 – 2008 [12]) defines the cooling season with a using time of 1136 hours. The difference in cooling hours leads to different SEER results. Generally, the resulting SEER based on the GB/T 7725 – 2004 is higher than the SEER based on the GB 21455 – 2008. The China energy labeling program adopted GB 21455 – 2008 as the basis of its labeling scheme. However, the manufacturers also indicate SEER of GB/T 7725 – 2004 on the nameplate of the product in parallel with GB 21455 – 2008. The conflicts and confusions should be fixed with the next revision of the standards.

Test of a Chinese high efficiency air conditioner according to four different measurement standards

Methodology

A very efficient split wall air conditioner found by Topten China was chosen for the compliance tests: KFR-26GW/02(R2DBPXF)-S1 produced by Haier. The China Household Electric Appliance Research Institute (Cheari, [24]), a central institution hosted by State-owned Assets Supervision and Administration Commission of the State Council and approved by the State Commission Office for Public Sector Reform, conducts the measurements.

Figure 5: Indoor and outdoor unit of the tested Haier air condtioner model

The product's cooling and heating function efficiency was measured according to the following four standards:

- The current European standard EN 14511 from 2007. This standard contains no part load conditions and the result is a non-seasonal Energy efficiency ratio (EER) and Coefficient of Performance (COP).

- The future European standard, also including part load conditions: the draft revised EN 14511 and prEN 14825 (part load conditions). The future EN 14825 contains the calculation formula for the seasonal energy efficiency ratio (SEER) and the seasonal coefficient of performance (SCOP).

- The Chinese part load measurement standards on which the China energy labeling program bases its compliance tests: GB 21455-2008 and GB/T 7725-2004. The results are SEER and HSPF (Heating Seasonal Performance Factor).

- The US-standard ARI 210/240-2008, which also includes part load condition and a SEER (BTU/Wh) and HSPF (BTU/Wh) calculation.

The three standards containing part load conditions require a different number of measurements at different work loads or frequencies (Tab. 6).

Tab. 6: Number of measurements required in the different standards

	Chinese	**European**	**US**
Cooling function	2	4	5
Heating function	3	6	6

Results

The resulting efficiency index values according to the four different measurement standards are shown in table 7 and figure 6, for both the cooling and the heating function.

Tab. 7: Efficiency index results according to the different measurement standards

Efficiency index values in W/W	cooling	heating
China (SEER / HSPF)[2]	6.21	3.96
Europe current (EER / COP)	4.9	4.91
Europe future (SEER/ SCOP)	8.56	5.55
USA (SEER / HSPF)	7.86	3.66

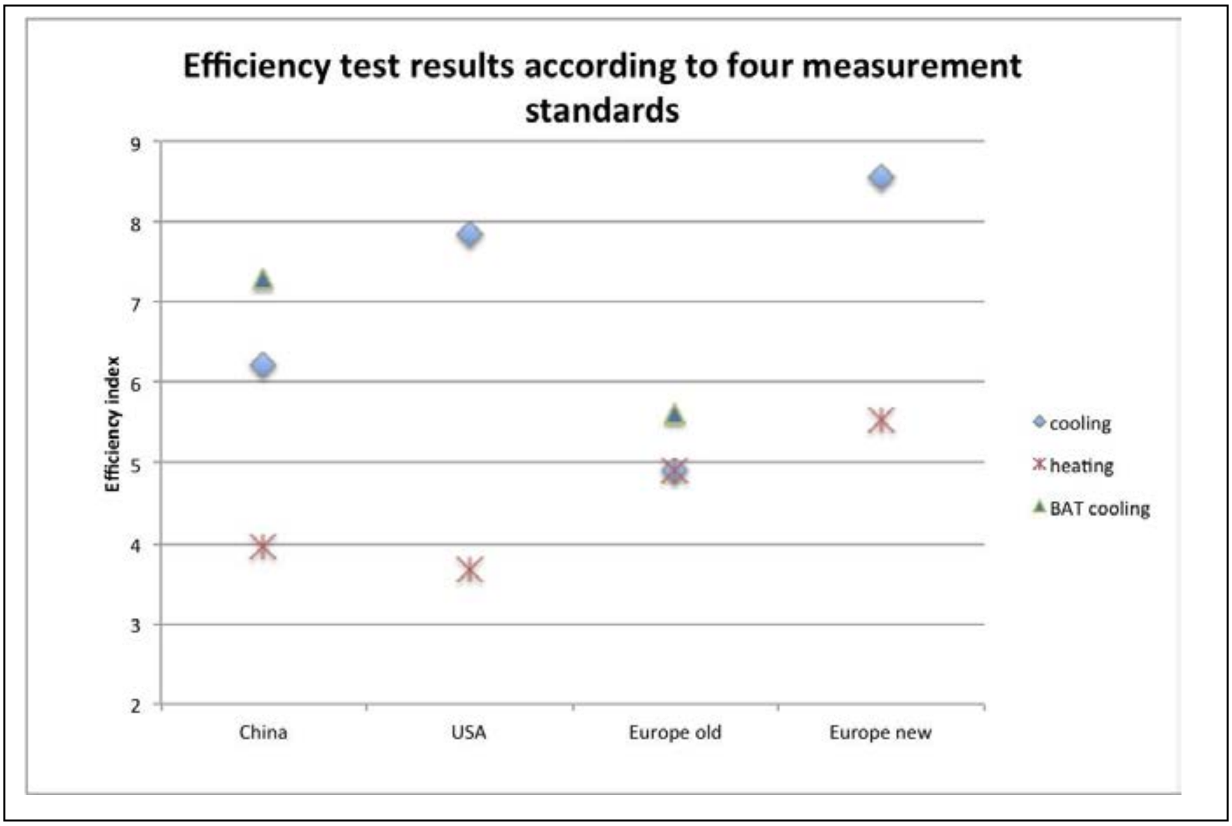


Figure 6: Resulting efficiency indeces of the test of one air conditioner model according to four different measurement standards and BAT values (cooling).

The result according to the Chinese standard confirms the manufacturer's declaration. The test result (SEER= 6.21) is 10% below the declared efficiency, but it's still within the measurement tolerance regulated in the standard (GB/T 7725-2004). The test result also confirmed the declared energy label grade 1; the result is clearly above the grade 1 threshold of 5.2.

The result according to the current European standard allows comparing the Chinese air conditioner to the efficiency of European devices. 4.9 / 4.91 for EER and COP are high values and put the model among the efficient air conditioners on the European market. The most efficient air conditioner on the European market however reaches higher values (EER: 5.63. COP: 5.68), and on topten.eu there are 6 models of comparable capacity with EER and COP values above 5.

Very high values resulted from the measurement according to the draft future European standard. With the resulting seasonal efficiency indicators of 8.56 (SEER) and 5.55 (SCOP) the model reaches the proposed A+++ classes for both the cooling and the heating function. The difference between the full load and part load results (the current and the future standard) is vast: the resulting SEER is 3.6 points higher than the EER, the SCOP is 0.6 higher than the COP value.

---

[2] In Wh/Wh

The results according to the US standard are way beyond the Energy Star threshold for heat pumps and central air conditioners [25]. When comparing it to the Energy Star product list it seems that the tested model is more efficient than the BAT on the US market.

The lab further reported that the future European standard was the most complicated to measure according to. It requires a higher number of measurements at different work loads than the Chinese standard (see Tab. 6). When measuring according to the Chinese or the US standard, measurements are conducted at certain different frequencies, while following the European standard a certain work load has to be set. This was reported to be more difficult than to set a certain compressor frequency. The accuracy however was thought to be the best according to the European standard.

Conclusions

The relevance of air conditioners for electricity consumption will increase, as sales are on the rise. Especially the Chinese market with sales about 7 times as high as in Europe is of crucial importance. Reversible models dominate both markets; variable speed air conditioners have an increasing market share in China and an already high market share in Europe. The heating function must not be neglected: it is responsible for two thirds of the energy consumption by air conditioners, at least in Europe.

The introduction of MEPS for variable speed air conditioners in 2008 and the energy label in 2009 triggered a considerable market share increase of variable speed air conditioners in China, additionally their average efficiency increased by up to 16% from 2008 to 2009. The implementation of policy measures affecting the generally efficient sector of variable speed air conditioners has proven to have a positive influence on the average efficiency and the market. Similar positive effects can be expected in Europe, if strict minimum efficiency requirements and an effective energy label are introduced.

Markets differ strongly regarding the refrigerants: apart from R410A, the ozone-depleting R22 is still widely used in China, while it is being phased out in Europe since more than 10 years. Experiences from Europe show that not only R410A is a good alternative to R22, but also natural refrigerants with low global warming potential such as propane and CO_2 are promising candidates.

The test results presented here allow to compare efficiency levels of Chinese air conditioners to those of European models. As there are also a few even more efficient air conditioners on the Chinese market than the tested model, the BAT in both regions seems to be more or less comparable.

The results according to the Chinese standard proved correct declaration and compliance, but point out the problematics of the high measurement tolerances allowed. In Europe the same problem exists: the current tolerance of 15% enables manufacturers to declare the efficiency of their products up to two classes above the real efficiency. The new EU label proposal now suggests a reduction of the measurement tolerance.

The high very SEER and SCOP values when measured and calculated according to the future European standard and the vast difference between the full load and part load results are quite surprising. For other efficient variable speed drive air conditioners similar differences can be expected. As there are more efficient air conditioners on the European market than the one tested, even higher SEER and SCOP values will be reached. If the differences of 3.6 between EER and SEER and 0.6 between SCOP and COP are applied to the very best model on the EU-market, this model can be expected to reach an SEER value of 9.2 and a SCOP of 6.3. At least five additional models can be expected to reach SEER values above 8.5 and SCOP above 6.
According to the proposed energy label scheme, the A+++-threshold would be at SEER=8.5 and SCOP = 5.1. With these class limits, there are several models in the A+++ classes for both the cooling and the heating function right at the introduction of the new label. Furthermore, the energy label still has different classification schemes for split air conditioners and the inefficient single and double ducts. A class A single or double duct with an EER of 2.6 appears to be more efficient than a split air conditioner of class B – which however with an EER of 5.0 really can be almost twice as efficient as the generally inefficient moveable appliance. At the same time classes below C (cooling) and A (heating function) will be useless after 2014 when the proposed efficiency requirements are in force. Such an energy label does rather contribute to consumer confusion than guide them to the most

efficient products. It also offers no incentive to manufacturers to develop and market more efficient products.

We are strongly recommending that the chances of future (EU or other) energy label revision processes is taken to define one single labeling scale for all types of air conditioners, with class limits guided by the BAT. Low classes should not be empty in the near future, and the A+ classes should be reserved for future technology developments. Such a label would allow consumers to see the low efficiency levels of single and double ducts and effectively guide them towards the BAT products.

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission's Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in two more European countries (www.topten.eu).
- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.
- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation - www.repic.ch) and SECO (State Secretariat for Economic Affairs - www.seco.admin.ch) who supports the build-up of Topten China.

References

[1] International Energy Agency IEA, Efficient Electrical End-use equipment (4E), Mapping and Benchmarking: Residential air conditioners. February 2011. http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=4

[2] Riviere et al.: *Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation).* Tasks 1 - 8, 2008 / 2009. http://www.ecoaircon.eu/

[3] Attali, Bush, Michel: *Factors influencing the penetration of energy efficient electrical appliances into national markets in Europe*. Report for Defra / the Market Transformation Programme by SoWATT and Bush Energie GmbH, 2009.

[4] Bertoldi P. and Atanasiu B., JRC: *Electricity Consumption and Efficiency Trends in European Union – Status Report 2009.* http://re.jrc.ec.europa.eu/energyefficiency/pdf/EnEff_Report_2009.pdf

[5] Topten.eu – Best products of Europe: www.topten.eu (yet topten.info, will soon change to topten.eu)

[6] Eric Bush, Sophie Attali, Conrad U. Brunner, Norman Dean, Anne Arquit Niederberger, Hu Bo: *Topten: Global Project for the Most Energy Efficient Products*. EEDAL 2011, Copenhagen.

[7] Sophie Attali, Eric Bush, Norman Dean, Hu Bo: *Topten Europe, USA and China – Reaching a critical mass to face the global appliance market.* Eceee summer study 2011, France.

[8] European Commission, Air conditioner impact assessment, 2011. Not yet published.

[9] China national institute of standardization (CNIS): *White paper for the energy efficiency status of China energy-use products*, 2010.

[10] State information center, China household electrical appliances association: White paper for the 2010 cooling year air conditioner market research, P11.

[11] ZOL, 2010

[12] GB 21455 – 2008. The minimum allowable values of the energy efficiency and energy efficiency grades for variable speed room air conditioners

[13] China energy labeling program. Implementation scheme for variable speed air conditioners, http://www.energylabel.gov.cn/NewsDetail.aspx?Title=&CID=49&ID=540

[14] National promotion categories of energy conservation techniques, http://hzs.ndrc.gov.cn/newzwxx/t20101208_385100.htm

[15] Topten China – Most efficient products of China: http://www.top10china.cn/english.html

[16] European Commission, Draft Working Document on Commission delegated regulation No …/… implementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners. November 2010.

[17] Michel, Bush, Nipkow, Brunner, Hu Bo, *Policy recommendations for air conditioners*. Topten International Group, 2011. http://www.topten.info/english/recommendations/policy-recommendations-room-air-conditioners.html

[18] European Commission, Draft Working Document on Commission delegated regulation No …/… implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans. November 2010.

[19] EN 14511-2007: Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. Terms and definitions, test conditions, test methods, requirements.

[20] prEN 14825, Draft: Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance

[21] GB 12021.3 – 2010. The minimum allowable values of the energy efficiency and energy efficiency grades for room air conditioners

[22] GB/T 7725 – 2004, Room air conditioners measurement standard

[23] China energy labeling program implementation scheme for fixed speed air conditioners, http://www.energylabel.gov.cn/NewsDetail.aspx?Title=&CID=49&ID=724

[24] China Household Electric Appliance Research Institute (CHEARI): http://www.cheari.org/english/index.aspx

[25] Energy Star key product criteria for air source heat pumps and central air conditioners. http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_crit_as_heat_pumps

Phasing out greenhouse-intensive water heaters in Australia

Dr George Wilkenfeld

Director, George Wilkenfeld and Associates

Abstract

Water heating accounts for nearly a quarter of greenhouse gas emissions from Australian households, a higher share than space heating and cooling. This is due to a historical preference for low-cost electric resistance water heaters and the high greenhouse gas-intensity of the electricity supply, over 80% of which is generated from coal.

Alternative water heating options such as natural gas (where supply is available), solar or heat pump can reduce greenhouse gas emissions from water heating by 50 to 60%. They cost more to purchase and install, but usually cost less to run. Government rebates for solar and heat pump water heaters have had some success in shifting the market, but at relatively high cost, due to the number of free riders and the tendency of suppliers to capture some of the rebate value.

Another approach is to regulate against the installation of electric water heaters. Several Australian states have already done so for new houses, and they are now planning to apply the same rules when electric water heaters need to be replaced in existing houses. This means that many households will need to spend more on their next water heater as a result of national greenhouse reduction policy.

This paper describes the development and implementation of the policy, including the cost-benefit modelling and other analyses which support it. There will be significant impacts on consumers, manufacturers and installers as the market is forced to gas, solar and heat pump water heaters.

There are also complex interactions with the economics of the electricity supply system, because Australia has one of the largest off-peak water heating loads in the world, and this will decline as electric resistance storage water heaters are phased out.

Policy Background

In December 2007, Australia ratified the Kyoto Protocol to the United Nations Framework Convention on Climate Change, agreeing to limit annual emissions to an average of 108% of 1990 levels during the Kyoto period (2008-2012). Projections released in March 2010 showed that Australia is on track to meet this target. Emissions are expected to average 581 Mt CO_2-e per annum over the five years of the Kyoto period, which is 106% of 1990 levels.[1]

The Australian Government has also unconditionally committed to reducing national greenhouse gas emissions by 5% below the 2000 level by 2020.[1] Emissions in 2000 were 553 Mt CO_2-e, so achieving the target will mean holding emissions to 525 Mt CO_2-e in 2020. The government estimates that reduction measures already in place would result in emissions reaching 669 Mt, so further measures amounting to 174 Mt are required (Figure 1). The task is made more challenging by the fact that population is projected to grow at a rate of about 1.3% per annum, so to meet the target, annual emissions per capita will have to fall by 20%, from 26.0 tonnes CO_2-e per capita in 2010 to about 20.9 tonnes in 2020.

The 5% reduction target is supported by both major parties in the Australian Parliament, but there are differences of opinion on the policies required to achieve it. The Labor government that was elected in August 2010 has set up a multi-party process to investigate the options for placing a price on

[1] The government has offered to set a greater reduction target, of up to 25% of 2000 emissions, subject to a number of criteria for international action being met (DCC 2010).

emissions, whether through a cap-and-trade scheme or an emissions tax.[2] The Liberal-National opposition does not support carbon pricing, but does support unspecified ‘direct action’ measures to achieve the 5% reduction target.[3]

The Commonwealth and State governments already have a large number of measures in place to reduce emissions. Their combined effect is illustrated by the difference between the ‘No Measures’ and ‘With Existing Measures’ lines in Figure 1. Some of these date from the 1980s, and many more have been introduced in the last decade.

The measures fall into three main categories:

1. Increasing the efficiency of energy use in appliances, equipment, buildings, industry and transport;

2. Promoting the use of renewable energy; and

3. Encouraging the use of lower-emissions fossil fuel energy sources in place of higher-emissions sources.

The third category is particularly significant for Australia, where over 80% of electricity is generated from coal, 15% from natural gas, and only 3% from renewables.[1] There is a legislated Renewable Energy Target (RET) with the aim of raising the renewable share of electricity generation to about 20% by 2020, and maintaining it at that GWh level until 2030. The scheme is underpinned by tradeable Renewable Energy Certificates (RECs).

Even if the RET targets are achieved, electricity generation is projected to remain greenhouse gas-intensive, so using electricity more efficiently, supplementing electricity use with direct solar thermal energy or substituting natural gas for electricity will give substantial greenhouse benefits.

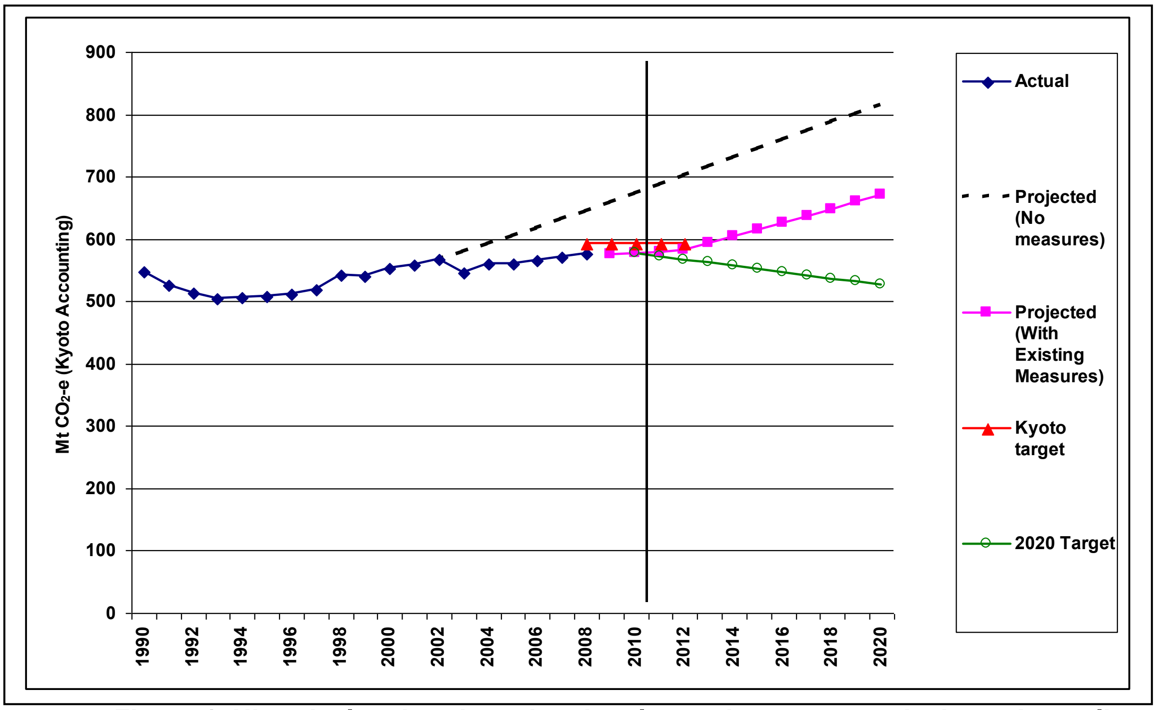


Figure 1. Historical and projected national greenhouse gas emissions, Australia

Residential Water Heating in Australia

Residential water heating offers significant scope for greenhouse reduction. In June 2010 Australia had a population of 21.99 million, living in 8.35 million households.[4] With holiday and second houses, and temporarily empty rental properties, there are about 9.3 million dwellings in all.

About 74% of dwellings are detached houses and a further 9% are semi-detached or attached ('terrace') houses. These house types are collectively termed 'Class 1' dwellings in Australian building codes. About 16% of dwellings are apartments ('Class 2') and 1% are other types. Virtually every Class 1 dwelling has at least one water heater. About 60% of Class 2 dwellings have their own water heaters, and 40% take hot water from a central system serving the entire apartment building.

About half of all water heaters in use are storage types with electric resistance elements; most of these are connected to off-peak electricity supply, and so benefit from lower tariffs (Figure 2). About a third are natural gas water heaters, of both storage and instantaneous ('tankless') designs. They are concentrated in the States which, for historical reasons, have the most developed natural gas networks: Victoria, Western Australia (WA) and South Australia (SA). The rest of the water heaters are liquefied natural gas (LPG), solar with either electric or gas boosting, and heat pump. The share of solar and heat pump has been growing rapidly in the last few years, for reasons described below.

About three quarters of the water heaters sold annually are for the replacement of existing water heaters (which typically fail after a service life of 10 to 12 years), and a quarter are installed in new homes or at the time of major building renovations. Market research has shown that the great majority of buyers are motivated by initial capital cost rather than running cost, and tend to install the cheapest type of water heater, even if it is more expensive to run over its operating life.[5]

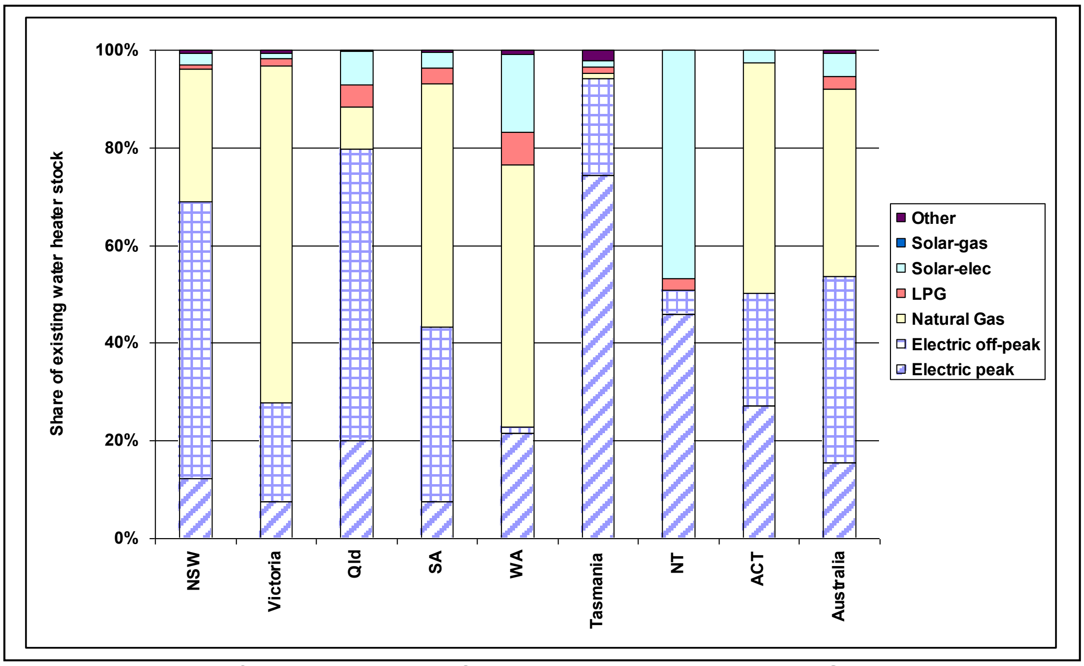


Figure 2. Types of Water Heater in Class 1 Dwellings, Australia, States and Territories, 2008

Greenhouse intensity of Water Heating

Water heating accounts for nearly 23% of the energy used in Australian households and about 22% of the greenhouse gas emissions from household energy use. About the same amount of delivered electricity is used as gas and LPG combined (this includes energy to boost solar systems), but as electricity is far more greenhouse-intensive, it accounts for nearly 80% of greenhouse emissions from residential water heating.

The Building Code of Australia (BCA), defines a 'greenhouse-intensive water heater' as one where the greenhouse intensity exceeds 100 g CO_2-e/MJ of thermal energy delivered by the water heater, taking into account both the form of energy used and the water heater's own performance and efficiency.

Figure 3 illustrates the emissions intensity of a range of water heater types, each delivering a 'medium' hot water load (40 MJ useful energy per day), in the States and solar zones which together cover about 85% of Australian houses. It shows that electric water heaters have by far the highest intensity, but the ranking and relative differences between the other technologies depend on the State and the solar zone. In Victoria for example, the predominant generation fuel is brown coal, giving it the highest intensity of electricity supply, and it is in a southerly solar zone, so solar water heaters tend to use more boosting energy.

In a household that currently uses an electric resistance water heater, emissions can be cut by 50% to 60% if that water heater is replaced by one using electricity more efficiently (e.g. a heat pump, which concentrates heat from the ambient air) or in combination with solar panels. Emissions can also be cut by using natural gas (if available) or LPG water heaters. If an electric water heater is replaced by solar-gas, emissions will be reduced by 80% or more.

Figure 3 shows that:

- Water heaters divide into two discrete groups according to greenhouse gas-intensity – conventional electric water heaters and all others;
- The differences in greenhouse-intensity between these two groups are greater than the differences within a technology type; and
- On this basis, electric water heaters constitute the 'greenhouse-intensive' group, so the objective of phasing out greenhouse-intensive water heaters can be achieved by phasing out electric resistance water heaters.

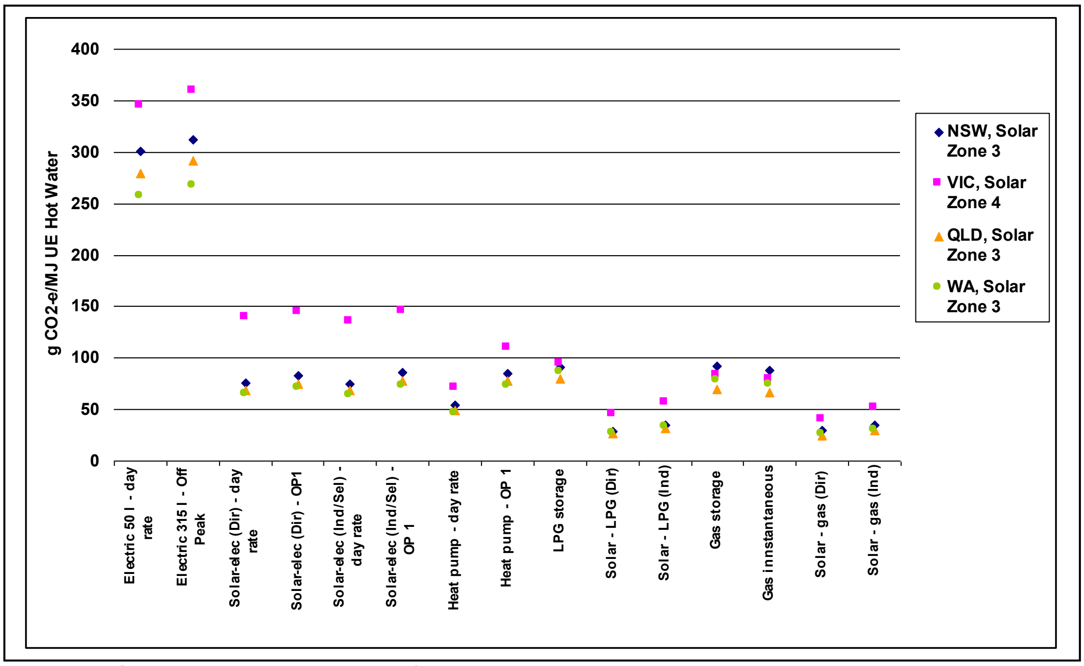


Figure 3. Greenhouse-intensity of various water heater

Dir = direct-heating solar panels. IND = Indirect-heating solar panels with heat exchange fluids, suitable for frost areas. Sel = Selective surface collectors. Greenhouse intensities, for those gas and solar-gas water heaters which use electricity for standby energy, fans or pumps include electricity-related emissions.

Interventions in the Water Heater Market

The design and selection of water heaters is subject to a range of government interventions, including energy labelling and Minimum Energy Performance Standards (MEPS). The Equipment Energy Efficiency (E3) program, managed jointly by the Australian Commonwealth, State, Territory and New Zealand governments, sets maximum heat loss levels for electric storage water heaters and performance standards for gas and LPG water heaters. There is also a star rating energy label for gas and LPG water heaters. The RET program has the effect of raising the performance of solar and heat pump water heaters, because it awards more saleable RECs to products with higher performance.

Information about the running cost advantages of solar and heat pump water heaters compared with conventional electric and gas water heaters is readily available. However, these options also have the highest capital costs (Figure 4), so even where users want to act on the information and obtain the advantage of lower running costs they must first spend more on their water heater than if they simply replaced, say, an electric with another electric.

Governments have recognised and sought to address this capital cost barrier. When solar and heat pump water heaters are installed they create RECs under the Renewable Energy Target program, which typically reduces the purchase price by between AUD 900 and AUD 1,400. This represents a cross-subsidy to solar and heat pump water heater buyers from all electricity consumers, since the costs of the RET scheme are ultimately passed through as higher electricity prices.

Even with the RET scheme however, the capital cost barrier remains – as shown by the fact that the subsidised capital components for the solar and heat pump options in Figure 4 are still significantly higher than the capital components for the electric, gas and LPG options.

Therefore several Australian governments instituted a second capital subsidy, paid by taxpayers (or in some States, from special levies collected from energy users). Unlike the RET scheme, these rebates are not legislated, so they and can be – and have been – changed or terminated without notice. Another key difference is that RECs can be created by all solar and heat pump water heater installations, including those in new homes, while rebates are usually available only to householders replacing an existing electric water heater with a solar or a heat pump.

The dollar values of rebates peaked during 2009 and have fallen considerably since. During the peak the Commonwealth offered a rebate of AUD 1,600 and the State of NSW offered up to AUD 1,200 to any householder replacing an electric water heater with a solar.[2] Together with the RECs value, this meant a capital subsidy of up to AUD 4,200 to a solar water heater purchaser. In 2009, buyers in some States could get nearly three quarters of the capital costs of a solar-electric and heat pump water heater back in subsidies.

These capital subsidy programs have clearly had an effect on the water heater market. In 2008, solar and heat pumps made up about 5% of water heater sales, but in 2009 the market share leapt to over 20%. While this may be seen as a success, it raised a number of issues, most of which have yet to be fully analysed:

- Financial sustainability: in the financial year 2008/09 – even before the surge in solar and heat pump sales – Australian governments collectively spent about AUD 81 million on rebates for replacement water heaters, apart from the administrative costs. (The cost to the RET scheme was a further AUD 63 million). These costs would have quadrupled in 2009/10. Not surprisingly, nearly every rebate scheme has since been terminated, considerably reduced in value, and/or a termination date has been announced;

- Free riders: many rebates have gone to buyers who would have purchased solar or heat pumps in any case;

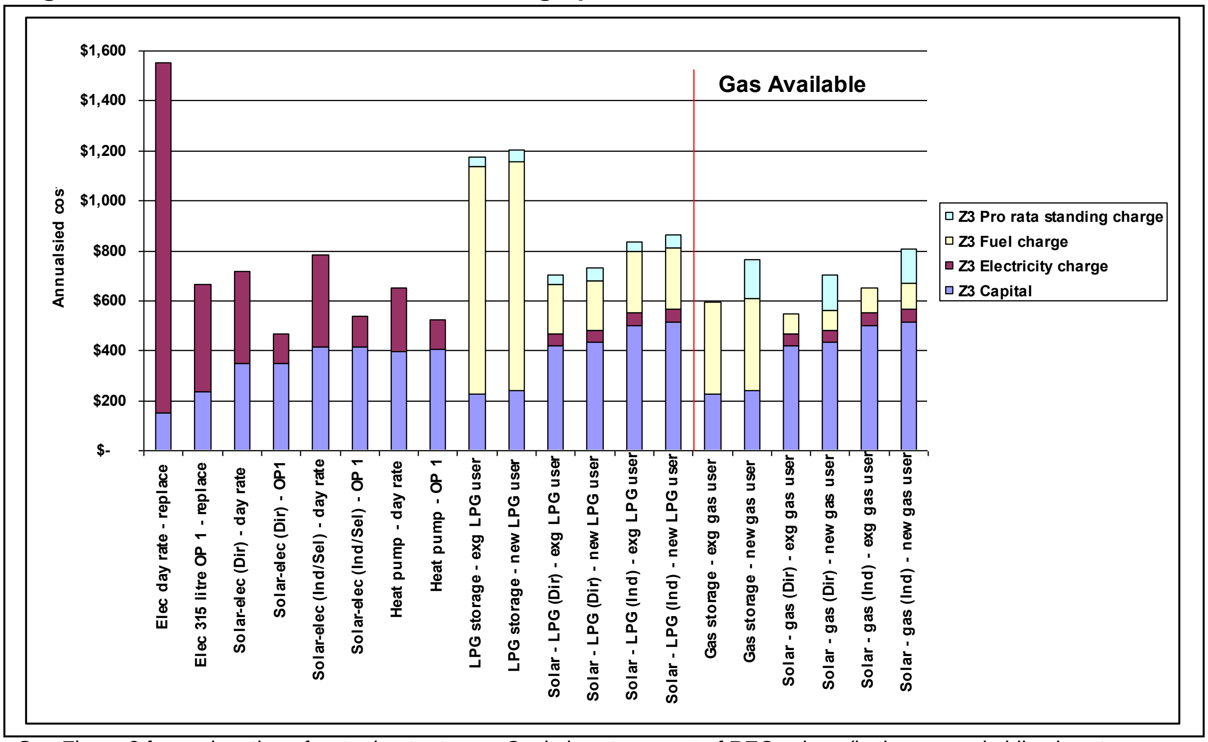
- Equity: in most rebate programs households had to raise the capital cost in the first place and then apply for the rebate, so low-income households with less access to capital were at a disadvantage. Some programs were designed so the rebate could be claimed at the time of purchase, but this created other issues (see next point);

- Retention of rebate value by suppliers: there is some evidence that a significant share of rebate value was retained as higher margins by manufacturers and/or installers – not necessarily as a deliberate strategy, but as a result of reduced price competition due to the availability of the rebates. Where rebates were paid up front (rather than reimbursed) more of the value may have been retained by the supplier.

---

[2] The Commonwealth rebate scheme, which is due to terminate in June 2012, now offers AUD 1,000 for solar and AUD 600 for heat pumps. The NSW rebate scheme, which is due to terminate in June 2011, now offers AUD 300 for solar, heat pump or gas water heaters.

Figure 4. Annualised cost of water heating options



See Figure 3 for explanation of water heater terms. Capital costs are net of REC values (ie they are subsidised costs, annualised over typical operating life of each technology, using 7% internal rate of return). Pro-rata standing charges is share of fixed charge in bill that is nominally allocated to the water heater. Values are for NSW energy prices and solar performance in Australian solar Zone 3. Options to right of line only available where there is natural gas.

Regulations impacting on water heater choice

Rebates have traditionally been directed at water heater replacements in existing homes. For new houses, most State building regulations now either prohibit the use of electric water heaters entirely, or strongly penalise their use under sustainability scoring criteria (Table 1). In some States different rules apply according to whether the home is built is in an area supplied with natural gas, or whether it is in a location classified as 'non-metropolitan'.

The diversity of State regulatory approaches has created some difficulties for building companies and water heater suppliers operating nationally. In order to rationalise these differences, a set of standard rules was included in the 2010 edition of the Building Code of Australia (BCA). This includes an objective definition of a greenhouse-intensive water heater (one exceeding 100 g CO_2-e/MJ), rather than just including or excluding technology types. However, most State have chosen to retain their own pre-existing regulations.

Table 1 Regulations Impacting on water heater choice in new and existing dwellings

Jurisdiction	New dwellings		Existing Dwellings	
	Cl 1 (houses)	Cl 2 (apartments)	Cl 1 (houses)	Cl 2 (apartments)
NSW	Implemented 2004	Implemented 2005	None	None
Victoria	Implemented 2005	none	None	None
Queensland	Implemented 2009	None	Implemented 2010	None
SA	Implemented 2008	None	Implemented 2009	None
WA	Implemented 2007	None	None	None
Tasmania	None	None	None	None
NT	None	None	None	None
ACT	Implemented 2010	None	None	None
National	BCA May 2010	None	Agreed at end 2010	None

The focus has since shifted to preventing the use of greenhouse-intensive water heaters in existing homes, which make up over 75% of the water heater market. Two States have already implemented rules for this purpose (Table 1). Governments therefore saw the development of consistent national rules as a priority, in order to prevent the proliferation of State and Territory regulations, as occurred with new construction. Although not envisaged as a policy objective at the time, the adoption of such regulations has also become urgent as the end of rebates approaches – with the removal of the subsidy carrot for selecting low-greenhouse water heaters, it may be necessary to strengthen the regulatory stick. Otherwise there is a high risk that the water heater replacement market will revert to its pre-rebate pattern of strong preference for electric water heaters, because of their low capital cost.

The National Phase-out Policy

The objective of phasing out greenhouse-intensive water heaters in a national basis was a policy of the federal Labor Party, which was elected to government in November 2007 (and re-elected in August 2010). Prior to the 2007 elections, the ALP stated its intention to:

> '…phase-out the installation of greenhouse-intensive electric hot water heaters in new and existing homes with access to reticulated natural gas by 2010, and as installations in all existing homes by 2012. Exemptions will be granted for dwellings where the installation of climate-friendly systems is impractical.'[6]

In December 2008 the Ministerial Council on Energy (MCE), comprising the energy ministers of the Commonwealth, States and Territories 'agreed to a number of important initiatives under the National Framework for Energy Efficiency including:…a National Hot Water Strategic Framework':

> 'The framework provides for the reduction of greenhouse gas emissions associated with water heating, through the specification of minimum energy performance standards for water heaters and the phasing out of conventional electric resistance water heaters (except where the emissions intensity of the public electricity supply is low), together with a range of information and education measures'.[7]

This commitment was reaffirmed by the Council of Australian Governments (COAG – the forum comprising the Australian Prime Minister, the Premiers of the States and the Chief Ministers of the Territories) under the National Strategy on Energy Efficiency published in July 2009.[8]

In 2008 a task force of Commonwealth, State and Territory officials was established to carry out the analyses required to enable Ministers to make a final decision on the implementation of the policy.

The process followed a formal regulatory impact assessment, consisting of the following stages:

1. Preparation of a Regulatory Impact Statement (RIS) for public consultation. This had to meet published quality and content criteria, and conformity with those criteria had to be certified by the Commonwealth agency that oversees all regulatory proposals. The Consultation RIS was published in December 2009 [9];

2. A public consultation period, during which the project team gave presentations on the RIS at public information forums in all capital cities (other than in Tasmania, the government of which has chosen not to implement the proposed measures); 82 organisations and individuals took part in the forums and/or made a written submission.

3. Revision of the analysis to take account of any changes in conditions (e.g. energy prices or relevant policy settings) and of issues raised during the public consultation period; and

4. Preparation of a Decision RIS for consideration by Ministers and senior officials. Again, this document had to be certified by the Commonwealth agency that oversees all regulatory proposals. The Decision RIS was submitted to Ministers and senior officials in December 2010 [10].

At its meeting on 10 December 2010, MCE 'agreed to the Decision Regulatory Impact Statements in relation to…the phase-out of Greenhouse-Intensive Water Heaters'.[11] The key recommendations in the Decision RIS were:

1. 'In view of the effectiveness of reducing emissions, and the overall cost-effectiveness for householders, greenhouse gas-intensive water heaters should be phased out from Class 1

buildings (i.e. houses) through prohibiting the installation of electric resistance water heaters, with certain exemptions.

2. In view of the advantages of a staged implementation, the phase-out should be implemented in two stages; the first stage from 2010 and the second from 2012.

3. In view of the time required to develop uniform national regulations, each Australian jurisdiction should implement the first stage under its own plumbing regulations, and the second stage through common provisions, such as those which may be developed for the Plumbing Code of Australia.

4. Each jurisdiction should determine its own rules for the first stage of implementation, based on criteria such as location and/or gas connection status, targeting houses where compliance options are likely to be wider and cheaper.' [10].

The Ministerial agreement cleared the way for officials to plan the detailed implementation of the phase-out.

Modelling the Impacts

The exclusion from the market of a type of product which accounts for about half of all current sales obviously requires very careful consideration. The analysis was more complicated than for conventional energy efficiency measure such as MEPS, because it involved hypotheses about how consumers in a constrained market (ie with electric water heaters no longer an option) would select from different energy forms and product types, not just different energy efficiency levels.

In Australia, cost-benefit modelling of energy efficiency proposals is always carried out on a State and Territory basis and then aggregated to the national level.[3] In addition, the impacts of the phase-out were separately modelled for regions with natural gas available and those without, because household in the latter areas will be required to select from options with a high capital cost (e.g. solar-electric, solar-LPG) or a high running cost (conventional LPG, which costs about three times as much as natural gas per energy unit). The modelling was also carried out by household income strata and for owner-occupiers and tenants separately, to better understand the impact on low-income households,

It was not possible to use the evidence of recent buyer preference as a guide to likely future behaviour, because the water heater market has been so heavily influenced in the past few years by the availability of the cash rebates described earlier. It was necessary to develop a complex buyer decision model, which embodied the market characteristics identified in consumer research – a strong tendency to replace a failed water heater with another of the same type, and subjective discount rates which vary according to income levels.

During 2010 there were a number of important developments which required re-runs of the modelling between the Consultation RIS and Decision RIS stages. The Commonwealth government abandoned its plan to implement a national emissions trading scheme in 2010, following rejection of the legislation by the upper house of the Parliament. As the electricity price projections used in the modelling include the impacts of carbon pricing, these had to be revised to reflect the probability that there would be no carbon pricing before 2013 at the earliest.

Also in 2010, the national electricity price regulator awarded unexpectedly high increases in network charges, for reasons quite unrelated to carbon pricing: the need to replace ageing network infrastructure, the need to accommodate rapid population growth and growing peak demand, largely driven by household air conditioning. These increases meant that electricity price projections were significantly higher in the Decision RIS than in the Consultation RIS, despite the delay in the implementation of carbon pricing: about 14% higher by 2020, and 29% higher by 2030.

---

[3] Where a policy proposal covers New Zealand as well, it is also modelled separately. New Zealand is not involved in the present proposal.

Another key aspect of the cost-benefit modelling was the exclusion of the effect of rebates. This proved to be a wise decision, because as we have seen, these have become financially unsustainable for governments, and are rapidly winding down. However, the effects of the capital subsidy to solar and heat pump water heaters from the creation of RECs (about AUD 900 to 1,400 per unit) was included, because the RET scheme is legislated to continue to 2030.

Figure 5 shows the projected stock of water heaters in use in houses over the period 2010-2030, in the absence of legislation to phase-out greenhouse-intensive water heaters. The number of electric water heaters would fall as the share of solar and heat pump rises, but electric storage would still remain the most popular water heater type. Figure 6 shows the projected impact of the phase-out. Electric water heaters virtually disappear by 2020, when the last of the existing units retires from service (Tasmania, which is not participating in the phase-out, accounts for the small continuing stock). The sales that would have gone to electric water heaters must be diverted elsewhere, so natural gas, LPG, solar and heat pump water heaters all gain market share.

This change in the market, large as it is, will be less disruptive for water heater manufacturers and suppliers than might be thought. All local manufacturers of electric water heaters also make solar, heat pump or gas water heaters – in some cases all of these. Furthermore, the components of electric water heaters that require the most complex and capital-intensive production methods, the pressure tanks, can also be used in solar and heat pump water heaters, so given sufficient notice the manufacture of key components can adjusted.

There is a risk that the import of tankless gas and LPG water heaters, which are not made in Australia, could increase, but it is projected that any losses to local manufacture will be more than made up by gains to the water heater installation industry, because the installation of gas, heat pump and – especially – solar water heaters is more labour-intensive than electric water heaters. There are already programs under way to alert plumbers and installers of the coming changes, and to ensure that there are enough personnel with the right skills to cope with them.

The average price of water heaters is of course projected to increase. Where buyers are denied the cheapest replacement option – an electric storage water heater – they will be forced to purchase a more expensive alternative. The increase in average water heater capital cost (include both purchase and installation) is estimated to be in the range AUD 90 (a 6% increase) and AUD 450 (a 26% increase). The projected increase is relatively low because it is expected that buyers will choose the least expensive complying option available, which will often be natural gas.

In general, the lifetime energy cost savings for a gas or solar-electric water heater will more than compensate for the higher capital cost when compared with the electric option, given the steep rises in electricity tariffs locked in as a result of price regulator rulings. Therefore prohibiting the greenhouse-intensive electric option actually makes householders better off financially. The projected ratios of national benefits to costs are in the range 2.8 to 3.9.[4]

Nevertheless, the need to pay more when a water heater fails will cause hardship to many low-income households. Although it was not part of this analysis, governments are well aware of the need to consider assistance programs targeted to low-income households, possibly through the filter of household income tests (which were in fact used in the early days of some rebate programs, but then abandoned in favour of unrestricted access). Preliminary calculations suggest that the cost of well-targeted assistance will be far lower than the cost of untargeted rebates. In any case, the continuation of unrestricted rebates, even at their current much-diminished values, would be very costly to governments, given the projected increase in solar and heat pump takeup once the regulations take effect.

Government assistance is not the only option for addressing the capital cost issue. Financial institutions, or even water heater suppliers themselves, could offer financing packages under which the initial loan can be repaid as energy savings accumulate.

[4] Based on Net Present Values in 2010, at a discount rate of 7%, for all water heaters installed in existing (pre-2011) Class 1 houses in the period 2011 to 2030.

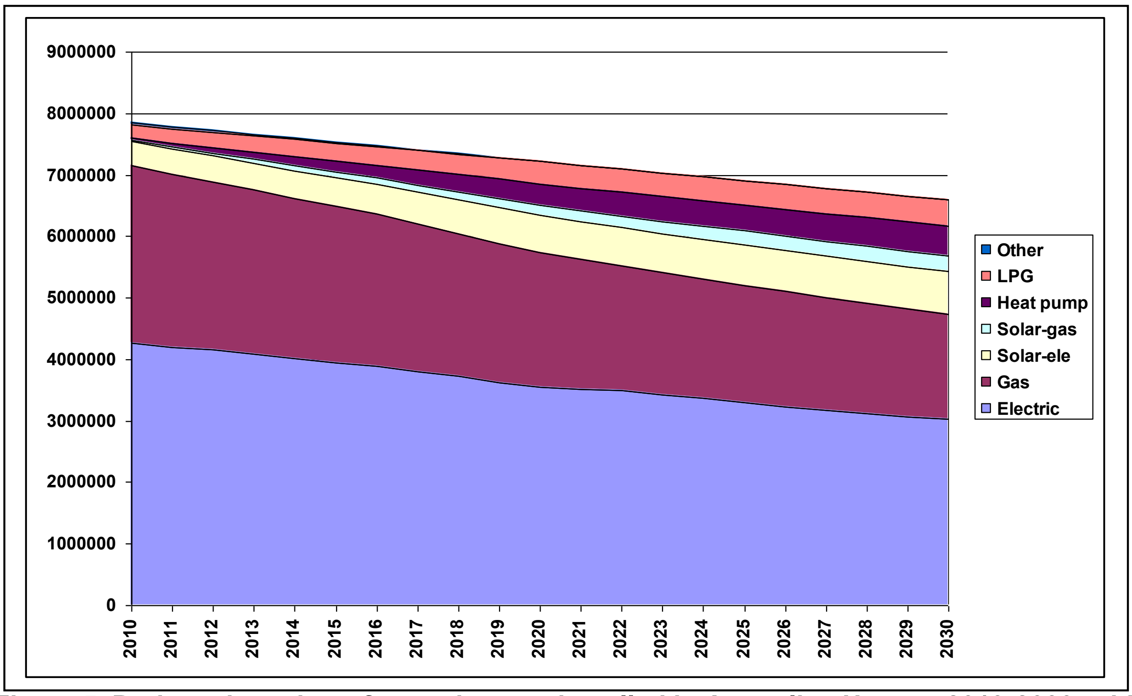


Figure 5. Projected number of water heaters installed in Australian Houses 2010-2030, without phase-out of greenhouse-intensive water heaters

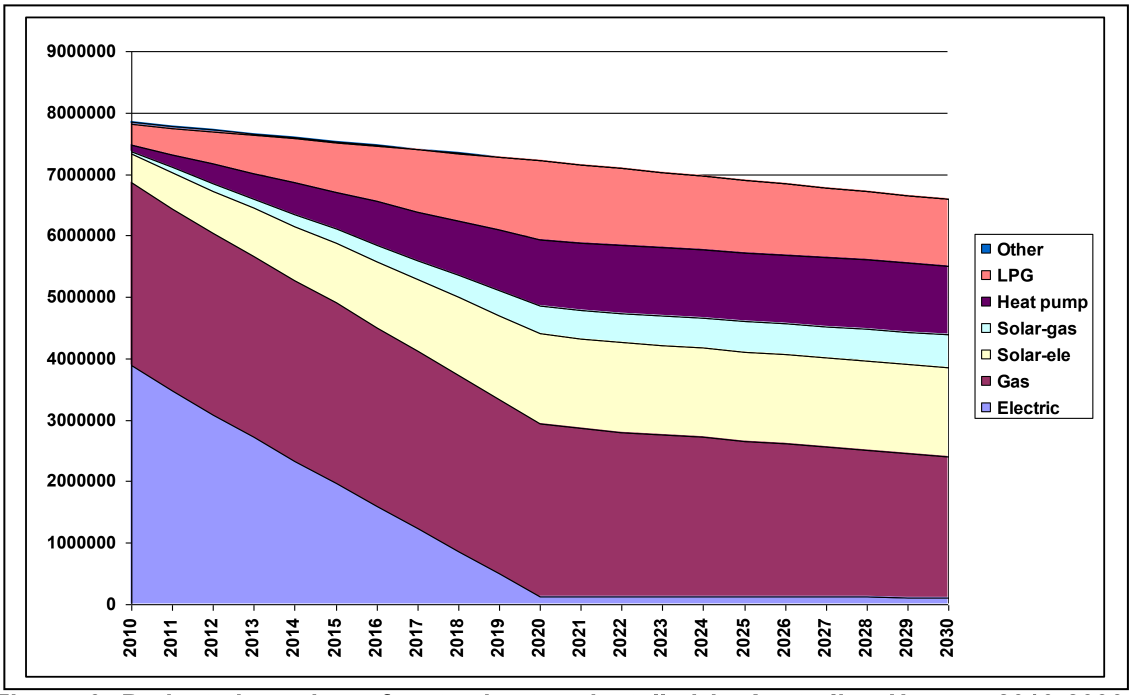


Figure 6. Projected number of water heaters installed in Australian Houses 2010-2030, with phase-out of greenhouse-intensive water heaters

Greenhouse Impacts

The ultimate objective of the phase-out is to reduce national greenhouse gas emissions compared with the ‘Business as Usual’ (BAU) case. Figure 7 illustrates the projected trend in emissions from water heating in houses that are in existence in 2010, and which remain substantially unrenovated.

(This excludes new and substantially renovated houses, which are covered by different regulations, and apartments).

The 'Models' A, B and C embody different combinations of assumptions. For each Model the critical indicator of greenhouse impact is the gap between the 'BAU' case towards the top of the graph and the 'phase-out' case below it The best estimate is that by 2020 the phase-out will reduce national greenhouse gas emissions by 4.2 to 4.3 million tonnes of CO_2-e emissions per annum, compared with the BAU case. The great majority of the decline will be due to the phase-out of greenhouse-intensive electric water heaters, but average emissions per house will also be reduced by gradual increases in the efficiency of the alternative water heaters (gas, LPG, solar and heat pump) and by rising efficiency of hot water use.

The measure is projected to reduce greenhouse gas emissions from water heating by nearly one third compared with BAU, or 79-82 Mt CO_2-e up to 2030. This would make it the largest household appliance greenhouse reduction measure currently available to Australian policy-makers.

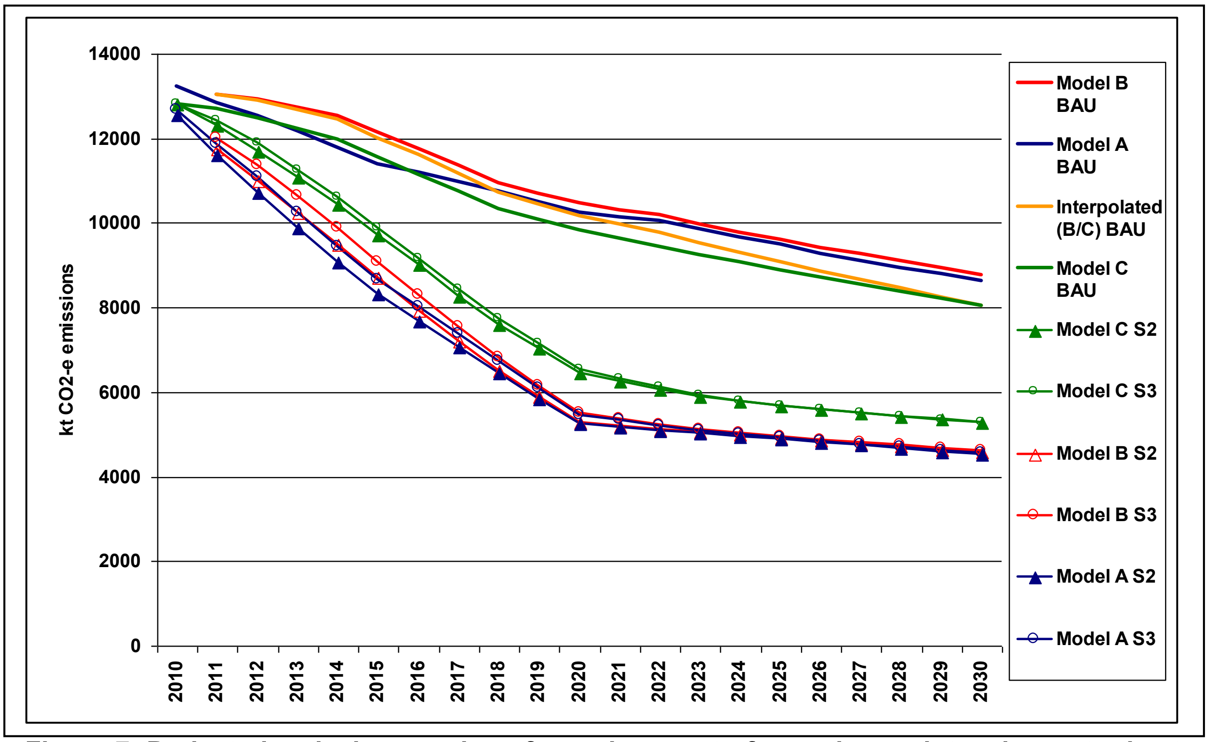


Figure 7. Projected emissions savings from phase-out of greenhouse-intensive water heaters
'Models' refer to different combinations of input assumptions

Peak Demand Issues

The phase-out of electric storage water heaters will have consequences for the management of the electricity supply system. Most electric water heaters are connected to 'off-peak' tariffs, under which they are only energised overnight, or energised at all times other than during the afternoon and evening peak. Either way, the network operators are assured that the water heater will not contribute to peak demand. In the case of overnight energisation, there is a further benefit to electricity generators of having a large thermal load at times when demand would otherwise be low.

New strategies are required to ensure that these benefits can be retained once electric water heaters are replaced by solar-electric and heat pump water heaters. These do not operate as well on off-peak tariffs, especially in winter. They will occasionally run out of hot water on winter evenings in the southern States – or else they will need to be oversized, and hence more expensive, to reduce that risk. To avoid the development of a new peaking problem, and to cost-effectively reduce the risk of running out of hot water, solar-electric and heat pump water heaters will need demand response capabilities, so they can be switched off briefly at times of network congestion.

Solar and heat pump water heaters can also act as heat sinks at times when generation wholesale prices are low, as can occur when there is a large amount of renewable generation such as wind available to the network. Australia is developing standards for electric, solar-electric and heat pump water heater demand response, which will include the capability of over-riding the normal thermostat settings to absorb additional energy when an external signal is received. These standards should adequately address the peak demand implications of the phase-out. They are also consistent with general electricity market trends towards smart grids, smart meters and more flexible time-based electricity pricing.

Comparison of Policy Options

Australian governments now have experience with a wide range of options which bear on the efficiency and selection of water heaters. These all have different characteristics, strengths and weakness, summarised in Table 2.

Some operate only within specific water heater types (e.g. MEPS), whereas most of the potential for greenhouse gas reduction in the water heater market comes from changing technologies (e.g. electric to gas, or electric to solar-electric). This can be done either by rebates, white certificate schemes or other cash incentive programs to overcome capital cost barriers, or by regulation. Rebate programs can be expensive, both in terms of overall cost to government and in terms of the share of value that does not go to households which need the rebate, but leak to free riders or water heater suppliers.

Table 2 Characteristics of programs bearing on water heater efficiency and choice

Program	Increases water heater efficiency	Effectiveness in overcoming capital cost barrier	Targeting	Cost to taxpayers	Cost to non-participants
Energy labeliing	Moderate	No	Moderate – few buyers see appliance (unlike whitegoods)	Very low – administration only	Very low – cost of labels and testing only, to buyers not using label
MEPS	Very effective – but only within types	Some effect in that price rises to cost-effective point - but only within types	Effective – all buyers benefit	Very low – administration only	Very low – all water heater buyers can benefit
RECs for solar and heat pump (based on RET scheme)	Some effect for solar & heat pump, because more effcient models get more RECs	Effective, but value can change with REC market price. Some value leaks to suppliers	Some benefits go to 'free riders' who would have purchased anyway	Very low – administration only	Moderate to high – all electricity users pay for RECs, whether they benefit or not
Government cash rebates - unrestricted	Some effect if qualifying models must meet efficiency criteria	Effective, but some value leaks to suppliers. If paid after purchase, harder for low-income groups.	Some benefits go to 'free riders'	Potentially very high, in both administration cost and rebate value. Amounts can be fine-tuned	All taxpayers meet cost, whether they benefit from rebates or not
Government cash rebates – restricted (eg to low-income groups)	Some effect if qualifying models must meet efficiency criteria	More effective – can directly benefit target group	Less benefits go to 'free riders' Low-income groups can be targeted	Costs are more controllable, but administration more complex. Amounts can be fine-tuned	All taxpayers meet cost, whether they benefit from rebates or not
Mandatory rules for water heater selection	Some effect if qualifying models must meet efficiency criteria	Effective in that buyers are forced to overcome cost, but low-income groups will need assistance	Impacts equally on all water heaters buyer	Low – mainly for compliance regime	None

Ultimately, no single policy or program meets all objectives, and several different approaches are needed in parallel. For example, the proposed regulated phase-out could be accompanied by a restricted rebate regime which targets those low-income households which have difficulty meeting the higher capital cost of a complying water heater. There are also many design options and possibilities within each program. For example, if rebates are to continue in some form, it may be possible to offer the same cash amount for any complying non-greenhouse-intensive option, rather than favour any particular technology types, so that householders were encouraged to select the least costly compliance measure. All of these matters are still to be considered.

References

[1] *Australia's Fifth National Communication on Climate Change: A report under the United Nations Framework Convention on Climate Change*, Department of Climate Change, 2010.

[2] http://www.climatechange.gov.au/government/initiatives/multi-party-committee.aspx

[3] http://www.liberal.org.au/Issues/Environment.aspx

[4] http://www.abs.gov.au/ausstats/abs@.nsf/mf/3236.0

[5] *Regulation Impact Statement: for Consultation - Phasing Out Greenhouse-Intensive Water Heaters in Australian Homes*, George Wilkenfeld and Associates, with National Institute of Economic and Industry Research and Syneca Consulting, for Department of the Environment, Water, Heritage and the Arts, December 2009

[6] *Labor's 2020 Target for a Renewable Energy Future*, October 2007

[7] Ministerial Council on Energy Communiqué, Adelaide, December 2008

[8] *National Strategy on Energy Efficiency*, Council of Australian Governments, July 2009

[9] *Regulation Impact Statement: for Consultation - Phasing Out Greenhouse-Intensive Water Heaters in Australian Homes*, George Wilkenfeld and Associates, with National Institute of Economic and Industry Research and Syneca Consulting, for Department of the Environment, Water, Heritage and the Arts, December 2009

[10] *Regulation Impact Statement: for Decision - Phasing Out Greenhouse-Intensive Water Heaters in Australian Homes*, George Wilkenfeld and Associates, with National Institute of Economic and Industry Research, for the National Framework for Energy Efficiency, November 2010

[11] http://www.ret.gov.au/Documents/mce/_documents/2010%20bulletins/24th_Meeting_Communique_10Dec2010.pdf

Development and Evaluation of New Testing Protocols for Measuring the Performance of Showerheads in the United States and Canada

Robert Mowris, Verified, Inc.

Ean Jones, Verified, Inc.

Brian Woody, Verified, Inc.

Abstract

Showering in the United States consumes 15 to 20% of total residential indoor water use or 5.11 trillion liters per year. The current US showerhead standard is 9.46 liters per minute (lpm) at 550 kPa flowing pressure. The US Environmental Protection Agency (EPA) collaborated with the American Society of Mechanical Engineers and Canadian Standards Association Joint Harmonization Task Force to develop new showerhead test protocols for flow rate, force, and coverage over a range of flowing pressures from 140 to 550 kilopascal (kPa). Based on the new test protocols US EPA developed a WaterSense® showerhead specification of 7.6 lpm at 550 kPa flowing pressure which is 20% lower than current standards. This study provides laboratory test data and consumer satisfaction survey results for 43 efficient and 30 standard showerheads to evaluate the new test specifications. Approximately 64 to 77% of tested showerheads do not meet the WaterSense® specification. Based on these findings, this study recommends that California not adopt the lower flow rate standard specified in the California Green Building standards. Instead, the study supports the voluntary WaterSense® specification to give manufacturers time to design more efficient showerheads. The study identified seven showerheads with low flow rates that meet the WaterSense® criteria and have "buy" consumer ratings. These efficient low-flow WaterSense® showerheads use innovative spray designs and pressure-compensating flow technologies. Annual savings from improved showerhead standards and labels are estimated at 245 billion liters of water, 19.83 PJ, 3,066 GWh, 3.265 million tonnes of carbon dioxide, and $600 million (USD) per year.

Introduction

Showering in the United States (US) consumes 15 to 20% of total residential indoor water use or approximately 5.11 trillion liters of water per year [1]. The benchmark for showerheads, as specified in the Energy Policy Act of 1992, is a maximum of 9.46 liters per minute (lpm) [2.5 gallons per minute (gpm)] when measured at a flowing pressure of 550 kPa [80 pounds per square inch gauge (psig)], as determined through testing per the American Society of Mechanical Engineers (ASME) and Canadian Standards Association (CSA) A112.18.1/CSA-B125.1-1996 [2]. The California Green Building Standards include a mandatory prescriptive approach for showerheads of 7.6 lpm at a flowing pressure of 550 kPa [4]. However, due to poor showerhead performance and user dissatisfaction, residential and non-residential consumers have replaced single showerheads with multiple showerheads that may use more than the maximum water flow regulations intended. Consumers replace single showerheads with multiple showerheads to increase flow, coverage, force or other attributes that result in a better shower experience. Another reason is to obtain a therapeutic experience similar to a whirlpool tub or spa.

Consumer preferences have been analyzed in studies by manufacturers, hotel chains, and utility companies [8]. One study found 66% of respondents wanted more water flow and 60% wanted more force. One large US hotel company tested more than 150 showerheads before deciding to install custom-designed showers having two heads. Another US hotel company installed single showerheads in each room after testing showerheads with more than 7,000 guests who rated them on water pressure, coverage, and flexibility of spray settings [6].

The water and energy savings associated with development of new testing protocols to improve showerhead performance can be inferred from a report entitled, Trends in Shower Design and Their Effect on Energy and Water Use, published in the Proceedings of 2006 ACEEE Summer Study on Energy Efficiency in Buildings [1]. The potential water savings from improved showerhead performance to counteract the trend to multiple showerheads is estimated at 670 million liters per day or 245 billion liters per year. The potential annual energy savings from improved showerhead performance are 19.8 PJ, 3,066 GWh, and $600 million. The savings in California would be roughly 10% of these savings or 24 billion liters per year, 1.98 PJ per year, and 307 GWh per year. The net annual benefits to California are estimated at approximately $60 million.

This report provides market research, technical information, laboratory measurement data, and consumer satisfaction survey results from a three-year Public Interest Energy Research (PIER) study funded by the California Energy Commission (CEC) to collaborate with the American Society of Mechanical Engineers (ASME) and the Canadian Standards Association (CSA) Joint Harmonization Task Force to evaluate showerhead efficiency and performance, with the intent of developing new test protocols and the WaterSense® showerhead specification.

Joint Harmonization Task Force

The ASME and the CSA established a Joint Harmonization Task Force (JHTF) in 2007 with the intent of developing new showerhead test protocols and performance standards. The JHTF included showerhead manufacturers, water and energy utilities, testing laboratories, and consultants. The US Environmental Protection Agency (EPA) WaterSense® and their consultant, Eastern Research Group (ERG), worked with the JHTF to collaborate on new showerhead test protocols and the WaterSense® Specification for Showerheads [10]. EPA published its WaterSense® Notice of Intent (NOI) to develop a specification for high-efficiency showerheads in August 2007. In its notice, WaterSense® identified its goal to label products that are 20% more water-efficient than average products.

JHTF members identified a health and safety concern regarding the potential risk of thermal shock or scalding caused when a device using hot or cold water is activated while a shower is operating. Water can be diverted away from the shower fitting, causing a pressure drop in either the hot or cold water supply to the shower. A sudden temperature change can cause either an abrupt physical reaction resulting in a fall or scalding if the temperature increase is severe. To reduce temperature-related shower injuries, most U.S. plumbing codes require automatic-compensating valves that comply with ASSE 10162 or ASME A112.18.1/CSA B125.1 [3]. The JHTF evaluated temperature profiles associated with a drop in hot and cold water pressure for standard and efficient showerheads installed with and without auto-compensating valves designed for a flow rate of 9.46 lpm. The JHTF evaluated the data before it recommended a flow rate designation for high-efficiency showerheads.

The JHTF developed new showerhead test protocols to verify performance attributes in the laboratory. The JHTF conducted round-robin tests to evaluate the new test protocols with the same set of showerheads at multiple test laboratories including Robert Mowris & Associates (RMA). The set of 22 showerheads included in the round-robin tests are referred to as the “WaterSense®/ERG” models. ERG conducted consumer satisfaction testing on the same 22 showerhead models to determine whether there is a uniform preference or dislike of certain showerhead attributes and to determine whether the performance attributes adequately define user satisfaction (Wagoner 2008) [12]. RMA conducted consumer satisfaction testing to verify the ERG consumer satisfaction results for the “WaterSense®/ERG” models. RMA performed additional laboratory and consumer satisfaction testing on 51 other showerheads referred to as the “CEC PIER” models to evaluate how the new test protocols performed on a larger sample of showerheads. If the consumer testing provided conclusive results, the JHTF correlated these attributes against the laboratory test protocols and used the results to establish performance criteria for the new showerhead test protocols.

Project Advisory Committee

The project advisory committee (PAC) was organized in July 2007 and consisted of JHTF members including showerhead manufacturers, utility representatives, consultants, and industry experts. The

PAC met during JHTF meetings from July 2007 through January 2010. The PAC members participated in market research surveys, provided suggestions and specifications for the showerhead test protocols, designed showerhead test fixtures, provided showerhead models for testing, and performed round-robin testing of the test protocols. Round-robin testing of the showerhead test protocols provided feedback to improve the protocols. PAC members also provided review comments of the PIER study work products and reports.

Showerhead Market Survey

The showerhead market survey interviewed twenty five showerhead manufacturers, showerhead industry experts, water and energy utility representatives, testing laboratories, consultants, hardware and home improvement retail store representatives, and other water-efficiency and conservation specialists. The objective was to understand the showerhead market and obtain standard and water-efficient showerheads for laboratory testing and consumer satisfaction surveys.[1] Some manufacturers provided free samples for testing. Some products were purchased directly from manufacturers or through internet and retail stores. More than 100 showerheads were evaluated and considered and 73 showerheads were included in the study. The WaterSense®/ERG sample included 22 fixed showerheads and the CEC PIER sample included 41 fixed showerheads and 10 hand held showerheads. The WaterSense®/ERG showerheads were included in the round-robin laboratory testing by CSA, Alsons, IAPMO, and RMA and the WaterSense®/ERG and RMA consumer satisfaction survey. The CEC PIER sample of 41 fixed and 10 handheld showerheads were included in the RMA laboratory testing and RMA consumer satisfaction survey.

WaterSense®/ERG and CEC PIER Showerhead Samples

WaterSense®/ERG showerhead sample includes 22 showerhead models with 12 "poor performing" showerheads from several manufacturers, 5 showerheads of unknown performance, and 5 "control" showerheads selected based on success in several utility rebate programs and units frequently installed in hotel rooms. The WaterSense®/ERG models were selected to determine if users could uniformly differentiate qualitative performance and provide recommendations for showerheads to test quantitatively against the proposed ASME/CSA showerhead testing protocols in a laboratory setting. The WaterSense®/ERG consumer satisfaction survey study included a variety of showerheads with rated flow rates ranging from 2.65 lpm to 9.46 lpm at 550 kPa flowing pressure.

The CEC PIER showerhead sample includes 22 showerhead models from the WaterSense®/ERG sample plus 51 additional showerhead models including 41 fixed showerheads and 10 handheld showerheads with rated flow rates ranging from 2.08 to 9.46 lpm at 550 kPa flowing pressure. The CEC PIER sample included 43 efficient and 30 standard showerheads, and the WaterSense®/ERG sample included 13 efficient and 9 standard showerheads. The CEC PIER model samples were selected to compare and qualitatively and quantitatively test the EPA WaterSense® flow rate, force, and coverage criteria.

Retail Cost Survey

The retail cost survey for WaterSense®/ERG and CEC PIER model samples found an average retail price of \$49.68 ± \$3.04 per unit for standard 9.46 lpm showerheads with a sample size of 79 units. The average price for water saving showerheads is \$36.72 ± \$0.89 per unit and average rated flow rate of 5.6 ± 0.08 lpm at 550 kPa with a sample size of 196 units. The average retail cost of water saving showerheads are 26 percent less than the average retail cost of conventional showerheads

[1] "Water-efficient" showerheads are defined as 20 percent more efficient than standard showerheads, i.e., flow rate of 7.6 lpm or less at 550 kPa flowing pressure versus standard showerheads with flow rate of 9.46 lpm at 550 kPa flowing pressure. In addition, water-efficient showerheads must also meet the voluntary WaterSense® spray force and spray coverage specifications.

even from the same manufacturer. The market appears to value standard flow units at a premium price compared to water saving products, indicating a perception of inferior performance associated with water saving showerheads.

Description of the WaterSense® Showerhead Specification

WaterSense® Water Efficiency Flow Rate Criteria

The WaterSense® Specification for Showerheads requires measuring showerhead flow rates at flowing pressures of 20, 45, and 80 ± 1 psig (140, 310, and 550 ± 7 kilopascal [kPa]) with water temperature at 100 ± 10 °F (38 ± 6 °C) maintained for at least one minute (USEPA 2010) [11]. WaterSense® requires manufacturers to specify the maximum rated flow rate to be equal to or less than 2.0 gpm (7.6 liters per minute [L/min]) per the testing and verification protocols described in 10 CFR 430 Subpart F (DOE 1998), at flowing pressures of 20, 45 and 80 ± 1 psig (140, 310 and 550 ± 7 kPa). The minimum flow rate value, determined through testing, at a flowing pressure of 20 ± 1 psig (140 ± 7 kPa), shall not be less than 60 percent of the maximum flow rate value. The minimum flow rate value, determined through testing, at flowing pressures of 45 ± 1 psig (310 ±7 kPa) and 80 ± 1 psig (550 ±7 kPa), shall not be less than 75 percent of the maximum flow rate value.

WaterSense® Spray Force Criteria

The WaterSense® showerhead spray force is measured at a flowing pressure of 20 ± 1 psig (138 Pa ± 7 kPa). The minimum spray force shall not be less than 2.0 ounces (0.56 N) at a pressure of 20 ± psig (140 ± kPa) at the inlet, when water is flowing.

WaterSense® Spray Coverage Criteria

The WaterSense® showerhead spray coverage is measured at a water temperature of 100 ± 10 °F (38 ± 6 °C) maintained for at least one minute with water pressure at 45 ± 1 psig (310 ± 7 kPa) at the inlet when water is flowing per the new showerhead test protocol. The total combined maximum volume of water collected in the 2 and 4 inch (50, 101 mm) annular rings shall not exceed 75 percent of the total volume of water collected, and total combined minimum volume of water collected in the 2, 4, and 6 inch (50, 101, 152 mm) annular rings shall not be less than 25 percent of the total volume of water collected.

Manufacturer Survey Results

RMA conducted surveys with 25 manufacturers representing 80 to 90 percent of all showerheads sold in the US. Seventy one percent of manufacturers are members of the ASME/CSA A112.18.1 Joint Harmonization Task Force. Fifty percent of manufacturers are EPA WaterSense® partners. Twenty one percent of manufacturers are members of the US Green Building Council Water Efficiency Technology Advisory Group. The market share of the 24 manufacturers ranges from less than 1 percent to 12 percent and the average market share is 4 percent ± 1 percent. All manufacturers promote water conservation. Only one company reported receiving complaints (for another manufacturer valve) about thermal shock with their showerhead rated at less than 9.46 lpm at 550 kPa. Eighty eight percent of manufacturers have conducted showerhead quality tests using showerheads rated at less than 9.46 lpm at 550 kPa. Fifty percent of manufacturers give special guidance to consumers about retrofitting showerheads rated at less than 9.46 lpm at 550 kPa. Fifty eight percent of manufacturers reported 47% of total sales are water saving showerheads. Seventeen percent of manufacturers report that water saving showerheads cost more than conventional showerheads rated at 9.46 lpm at 550 kPa. However, the average retail cost for water saving showerheads is 26 percent less than conventional showerheads based on all showerheads in the survey. Eighty three percent of manufacturers sell water saving showerheads in California. Six manufacturers sell multi-shower units with average total sales of 3%. Forty six percent of manufacturers support a mandatory standard to reduce the maximum showerhead flow rate below 9.46 lpm to conserve energy and water. The manufacturers who support a mandatory standard for new construction represent a small market segment of less than 10 percent of the overall showerhead market share. Ninety six percent of manufacturers support the voluntary WaterSense® showerhead specification. Eighty three percent of manufacturers sell efficient showerheads with rated flow rates less than 9.46 lpm at 550 kPa and the average manufacturer offers 5 models. Fifty eight percent of manufacturers donated showerheads for testing in the CEC PIER study.

Water Efficiency Flow Rate Data

Laboratory and consumer test results for the WaterSense® flow rate criteria are shown in Table 1. Sixty four percent of WaterSense®/ERG models tested by CSA, IAPMO, and Alsons failed to meet required tolerance of the WaterSense® flow rate criteria (14 out of 22 models). Seventy seven percent of the WaterSense®/ERG models tested by RMA failed to meet required tolerance of the WaterSense® flow rate criteria (17 out of 22 models). Only 5 WaterSense®/ERG models tested by RMA pass the WaterSense® criteria while 17 fail due to the maximum measured flow rate at 550 kPa being greater than manufacturer specified flow rate, or minimum flow rate at 140 kPa being less than 60 percent of the maximum manufacturer specified flow rate, or measured flow rate at 310 kPa being less than 75 percent of the maximum manufacturer specified flow rate or not meeting the force or coverage criteria. Sixty six percent of CEC PIER fixed showerhead models tested by RMA failed to meet required tolerance of the WaterSense® flow rate criteria (27 out of 41 models). Eighty percent of CEC PIER hand held models tested by RMA failed to meet required tolerance of the WaterSense® flow rate criteria (8 out of 10 models). Only 16 CEC PIER models pass the WaterSense® specification while 27 fail due to the maximum measured flow rate at 550 kPa being greater than manufacturer specified flow rate, or minimum flow rate at 140 kPa being less than 60 percent of the maximum manufacturer specified flow rate, or measured flow rate at 310 kPa being less than 75 percent of the maximum manufacturer specified flow rate or not meeting the force or coverage criteria. Consumer satisfaction results are similar for the WaterSense®/ERG models with 64% and 59% "no buy." Consumer satisfaction results are lower for the CEC PIER fixed sample with 54% "no buy" and 10% "no buy" for the hand held models.

Table 1. Laboratory Test and Consumer Results for WaterSense® Flow Rate Criteria

Laboratory Test Sample	Sample Size	Failed Maximum Flow Exceeds Rated Flow	Failed Flow @ 140 kPa Less than Minimum	Failed Flow @ 310 and 550 kPa Less than Minimum	Percent Failed Water Sense Flow Rate Criteria	Percent Failed Consumer Satisfaction (No Buy)
CSA WaterSense® ERG	22	7	9	6	64%	64%
IAPMO WaterSense® ERG	22	6	12	7	64%	64%
Alsons WaterSense® ERG	22	7	9	7	64%	64%
RMA WaterSense® ERG	22	11	9	6	77%	59%
RMA CEC PIER Fixed	41	19	8	6	66%	54%
RMA CEC PIER Hand Held	10	6	2	2	80%	10%

Source: Mowris 2010 [7]

The most common showerhead failure was due to the maximum flow rate determined through testing at a flowing pressure of 550 ± 7 kPa being greater than manufacturer specified flow rate at 550 kPa as required in the WaterSense® Specification for Showerheads. One reason why so many showerheads fail the flow rate criteria could be the lack of government required third-party verification testing of maximum allowable flow rates. Other showerheads failed due to the minimum flow rate determined through testing at a flowing pressure of 140 ± 7 kPa being less than 60 percent of the maximum flow rate specified by the manufacture per the WaterSense® Specification for Showerheads. Other showerheads failed due to the minimum flow rate required in the WaterSense® Specification for Showerheads, determined through testing, at flowing pressures of 310 ± 7 kPa and 550 ± 7 kPa, being less than 75 percent of the maximum flow rate specified by the manufacturer per the WaterSense® Specification for Showerheads.

Spray Force Data

Laboratory test results for the WaterSense® water efficiency force criteria are shown in Table 2. Five percent of WaterSense®/ERG models tested by CSA (1 out of 22 models), 9 percent of the models tested by IAPMO (2 out of 22 models), and 23 percent of the models tested by Alsons and RMA (5 out of 22 models) failed to meet the required minimum WaterSense® spray force. Ten percent of CEC PIER fixed showerhead models tested by RMA failed to meet required minimum WaterSense® spray force criteria (4 out of 41 models). Ten percent of CEC PIER hand held models tested by RMA failed to meet required minimum WaterSense® spray force criteria (1 out of 10 models). The spray force test was difficult to perform consistently during the round robin testing due to problems with the calibration procedures which were improved in the final version of the test protocol. Alsons and RMA performed multiple laboratory tests using the final test protocol. Consumer satisfaction force results are higher for the WaterSense®/ERG models with 36% "failed." Consumer satisfaction force results are lower for the CEC PIER sample with 32% "failed" for fixed models and zero "failed" for hand held models. The percent of showerheads that failed the WaterSense® force criteria is 40% to 87% lower than the number that failed the consumer satisfaction force criteria. This is due to the minimum spray force criteria being 2.0 ounces (0.56 N). If the WaterSense® minimum spray force criteria were increased from 2.0 ounces to 2.6 ounces (0.73 N), then the number of showerheads that failed would be closer to the number that failed the consumer satisfaction force criteria. The JHTF members considered increasing the minimum force criteria to reflect user experience. JHTF members eventually agreed to the lower force threshold of 2 ounces (0.56 N), due to uncertainties associated with manufacturers being able to meet the combined flow rate, force and coverage criteria.

Table 2. Laboratory Test Results for WaterSense® Water Force Criteria

Laboratory Test Sample	Sample Size	Failed 0.56 N Force @ 140 kPa	Failed 0.64 N Force @ 140 kPa	Failed 0.73 N Force @ 140 kPa	Percent Failed WaterSense® Force Criteria	Failed Consumer Satisfaction Force Criteria
CSA WaterSense® ERG	22	1	2	5	4.5%	36%
IAPMO WaterSense® ERG	22	2	4	5	9.1%	36%
Alsons WaterSense® ERG	22	5	9	15	22.7%	36%
RMA WaterSense® ERG	22	5	10	12	22.7%	36%
RMA CEC PIER Fixed	41	4	7	11	9.8%	32%
RMA CEC PIER Hand Held	10	1	2	4	10.0%	0%

Source: Mowris 2010 [7]

Spray Coverage Data

Laboratory test results for the WaterSense® water efficiency force criteria are shown in **Table 3**. Eighteen percent of WaterSense®/ERG models tested by CSA, IAPMO, and Alsons (4 out of 22 models) failed to meet the required minimum WaterSense® spray coverage.[2] Nine percent of the WaterSense®/ERG models tested by RMA failed to meet the required minimum WaterSense® spray coverage criteria. RMA performed multiple coverage tests of each showerhead, and this explains the difference between RMA and other laboratory results. Ten percent of CEC PIER fixed showerheads tested by RMA failed to meet required minimum WaterSense® spray coverage criteria (4 out of 41 models). Ten percent of CEC PIER hand held models failed to meet required minimum WaterSense® spray coverage criteria (1 out of 10 models). Consumer satisfaction coverage results are higher for the WaterSense®/ERG models with 41% "failed" and 27% "failed." Consumer satisfaction coverage results are higher for the CEC PIER fixed sample with 22% "failed" and zero "failed" for hand held models.

---

[2] The WaterSense® coverage criteria combined maximum volume of water collected in the 2 and 4 inch (50, 101 mm) annular rings shall not exceed 75% of the total volume of water collected and; total combined minimum volume of water collected in the 2, 4, and 6 inch (50, 101, 152 mm) annular rings shall not be less than 25% of the total volume of water collected.

Table 3. Laboratory Test Results for WaterSense® Water Spray Coverage Criteria

Laboratory Test Sample	Sample Size	Failed WaterSense Coverage Criteria	Failed Consumer Satisfaction Coverage Criteria
CSA WaterSense® ERG	22	18%	41%
IAPMO WaterSense® ERG	22	18%	41%
Alsons WaterSense® ERG	22	18%	41%
RMA WaterSense® ERG	22	9%	27%
RMA CEC PIER Fixed	41	10%	22%
RMA CEC PIER Hand Held	10	10%	0%

Source: Mowris 2010 [7]

Consumer Satisfaction Survey

The WaterSense®/ERG and CEC PIER studies asked five survey questions using the same scoring criteria (see **Table 4**, Q1 through Q5). The CEC PIER study also asked participants to rate each showerhead on noise (Q6), overall satisfaction (Q7), and time required (seconds) to rinse a small amount of conditioner from their hair (Q8). The amount of conditioner is approximately 25 millimeters diameter in the palm of the hand (the size of one US Quarter). After applying the measured amount of conditioner to their hair, CEC PIER consumer survey participants entered the shower to rinse conditioner from their hair and press the "start" button on a waterproof wristwatch or stopwatch. When all conditioner is rinsed from the hair, the participant pressed the "stop" button and recorded "rinsing time" in the survey response form.

Table 4. Consumer Satisfaction Survey Questions

Q1 - Temperature (1=Excellent, 3=Poor) ___ (1 to 3)
Q2 - Force (1=excellent, 3=too soft or too hard)? ___ (1 to 3)
Q3 - Coverage (1=Excellent, 3=Poor)? ___ (1 to 3)
Q4 - Rinsing Action (1=Excellent, 3=Poor) ___ (1 to 3)
Q5 - Purchase showerhead (No Buy, Buy)? ___ (0 or 1)
Q6 - Noise (1=Quiet, 3=too loud)? ___ (1 to 3) CEC PIER Study Only
Q7 - Overall Satisfaction (1=Excellent, 3=Poor)? ___ (1 to 3) CEC PIER Study Only
Q8 - Rinsing Time to remove conditioner (seconds)? ___ CEC PIER Study Only

WaterSense®/ERG Consumer Satisfaction Survey Participants

The WaterSense®/ERG consumer satisfaction study included 38 participants from 22 households who were either employees of ERG or relatives of ERG employees. None of the participants work on the WaterSense® specification development. The 38 participants included 17 females and 21 males ranging in age from 22 to 78, with a majority falling in the 20 to 40 range. Participants were asked to measure the flow rate of their existing showerhead before installing the test showerheads to provide a baseline. Participants were asked demographic questions to understand user characteristics. Participants were informed that they would be testing a variety of showerheads with varying flow rates and performance characteristics and that their feedback was going to be used to help WaterSense® develop showerhead specifications. Participants were unaware they were intentionally testing some poor performing showerheads. Each household tested 4 showerheads for one week assigned at random. Participants rated each showerhead on force, coverage, temperature, noise, and overall quality by answering the first five survey questions described in **Table 1**. Nearly every household also tested a control showerhead. At the end of each weekly evaluation, participants were asked to provide feedback on the performance of the showerheads. Participants were also instructed to measure and record the flow rate of each showerhead at the end of the weekly evaluation period.

CEC PIER Consumer Satisfaction Survey Participants

The RMA CEC PIER consumer satisfaction survey included 34 females and 38 males ranging in age from 17 to 55. Surveys were conducted at a hotel located in Truckee, California. Participants were asked demographic questions before testing showerheads to understand user characteristics. Showerhead testing was conducted with participants who were given the choice of performing tests in one or more days. Participants tested and rated each showerhead based on temperature, force, coverage, rinsing action, purchase, noise, overall quality, and rinsing time by answering the consumer satisfaction survey questions described in **Table 4**. Consumer satisfaction testing was conducted in two phases. Phase I required 13 days with one 5-hour shift per day. Four participants tested 48 showerheads per shift during Phase I. Phase II required 7 days with two 3-hour shifts per day. Four participants each tested 25 showerheads per shift during Phase II. Each showerhead survey took approximately five minutes. Upon completion of a day of testing, participants returned the wristwatch or stopwatches and robes and were paid $20.00 for every hour of testing. Each CEC PIER participant tested 73 showerheads.

Consumer Satisfaction Survey Results for WaterSense®/ERG Models

WaterSense®/ERG and CEC PIER participants agreed on 80 percent of the models. Six models received a “buy” rating (including 3 efficient models) and 11 models received a “no-buy” rating from both participant groups. Participants disagreed on 2 standard models (A and E) and 2 efficient models (G and K). WaterSense®/ERG participants rated 64% “no buy,” while CEC PIER participants rated 59% “no buy.” Thirty-six percent of all models failed the consumer force rating, while only 4.5 to 23% failed the force test. Twenty-seven to 41% of all models failed the consumer coverage rating, while only 9 to 18% failed the coverage test. This shows an inconsistency between rated and measured input. The “no buy” rating for efficient models is 69% for both participant groups. The “no buy” rating for standard models is 56% for ERG participants and 44% for CEC PIER participants. Seventy-eight percent of standard models and 54% of efficient models failed the flow rate test.

The CEC PIER “no buy” rating is correlated to rinse time to remove hair conditioner in **Figure 1**. The polynomial curve fit has a 0.746 R-squared coefficient indicating 74.6 percent of the variation in “no buy” response is correlated to rinse time. The remaining 23.4 percent is due to variability in consumer preference.

Table 5. Flow Rates and Consumer Survey Results for WaterSense®/ERG Models

Showerhead Model	Rated Flow @ 550 kPa LPM	Tested Flow @ 550 kPa LPM	Pass Min or Max Flow Rate Test Criteria	ERG Consumer Satisfaction	ERG Consumer Rating	CEC PIER Consumer Satisfaction	CEC PIER Consumer Rating
A	9.46	8.82	Fail	33%	No Buy	50%	Buy
B	7.57	7.68	Fail	0%	No Buy	12%	No Buy
C	1.89	4.43	Fail	17%	No Buy	6%	No Buy
D	9.46	4.35	Fail	0%	No Buy	38%	No Buy
E	9.46	9.31	Fail	75%	Buy	44%	No Buy
F	3.79	2.95	Fail	29%	No Buy	12%	No Buy
G	5.68	6.21	Fail	17%	No Buy	54%	Buy
H	9.46	8.74	Fail	37%	No Buy	13%	No Buy
I	9.46	8.06	Fail	25%	No Buy	10%	No Buy
J	9.46	7.84	Fail	17%	No Buy	73%	Buy
K	6.06	5.94	Pass	60%	Buy	25%	No Buy
L	7.57	6.89	Pass	86%	Buy	60%	Buy
M	7.57	6.89	Pass	86%	Buy	67%	Buy
N	5.68	4.88	Pass	40%	No Buy	40%	No Buy
O	5.68	4.77	Pass	37%	No Buy	38%	No Buy
P	5.68	7.23	Fail	17%	No Buy	27%	No Buy
Q	5.68	7.23	Fail	57%	Buy	50%	Buy
R	9.46	9.08	Pass	89%	Buy	83%	Buy
S	9.46	8.44	Pass	100%	Buy	85%	Buy
T	5.68	6.81	Fail	0%	No Buy	12%	No Buy
U	5.68	6.89	Fail	43%	No Buy	33%	No Buy
V	9.46	9.16	Pass	80%	Buy	87%	Buy

Source: Mowris 2010 [7]

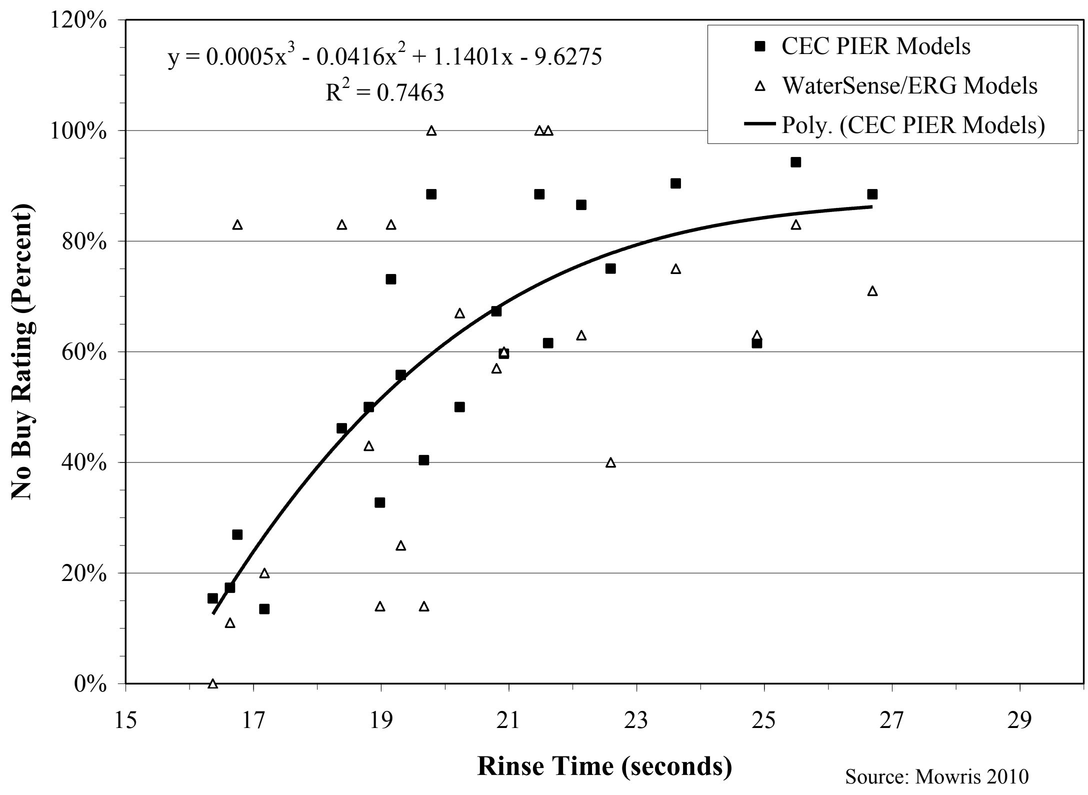


Figure 1. No Buy Rating versus Rinse Time for CEC PIER and WaterSense®/ERG

Consumer Satisfaction Survey Results for CEC PIER Models

Flow rates and consumer survey results for CEC PIER fixed models are shown in **Table 6**. Fifty four percent of models received a “no-buy” rating from participants, and 66 percent (19 models) failed the minimum or maximum flow rate test. Ten out of 31 efficient models received a “buy” rating. Thirty two percent failed the consumer force rating, while 10% failed the force test. Twenty two percent failed the consumer coverage rating, and 10% failed the coverage test. The “no buy” rating is 68% for efficient models and 10% for standard models.

Table 6. Flow Rates and Consumer Survey Results for CEC PIER Fixed Models

Showerhead Model	Rated Flow @ 550 kPa LPM	Tested Flow @ 550 kPa LPM	Pass Min or Max Flow Rate Test Criteria	CEC PIER Consumer Satisfaction	CEC PIER Consumer Rating
AA	2.27	3.41	Fail	0%	No Buy
AB	4.92	6.06	Fail	37%	No Buy
AD	7.19	9.08	Fail	27%	No Buy
AE	5.68	6.25	Fail	6%	No Buy
AF	5.68	6.81	Fail	19%	No Buy
AG	6.81	9.08	Fail	37%	No Buy
AH	7.57	11.36	Fail	27%	No Buy
AI	7.57	10.03	Fail	60%	Buy
AJ	5.68	6.25	Fail	19%	No Buy
AK	5.68	6.44	Fail	39%	No Buy
AL	9.46	12.49	Fail	90%	Buy
AM	5.68	6.81	Fail	10%	No Buy
AN	7.57	9.46	Fail	67%	Buy
AO	6.81	6.44	Pass	50%	Buy
AP	9.46	9.08	Pass	79%	Buy
AQ	9.46	6.06	Fail	54%	Buy
AR	5.68	6.44	Fail	63%	Buy
AS	9.46	6.06	Fail	56%	Buy
AT	9.46	8.71	Fail	62%	Buy
AU	5.68	5.68	Pass	65%	Buy
AV	6.06	6.06	Pass	17%	No Buy
AW	5.68	4.73	Fail	25%	No Buy
AX	7.57	9.08	Fail	73%	Buy
AY	9.46	9.08	Pass	69%	Buy
AZ	9.46	9.08	Pass	65%	Buy
BA	9.46	7.95	Pass	52%	Buy
BB	9.46	9.84	Fail	71%	Buy
BC	9.46	9.65	Fail	24%	No Buy
BD	6.81	6.25	Pass	65%	Buy
BE	6.06	1.89	Fail	19%	No Buy
BF	6.81	6.06	Fail	2%	No Buy
BG	6.06	5.3	Pass	33%	No Buy
BH	6.81	5.49	Pass	50%	Buy
BI	5.68	3.79	Fail	35%	No Buy
BJ	4.92	4.54	Pass	35%	No Buy
BK	5.68	4.73	Pass	45%	No Buy
BL	5.68	6.06	Fail	71%	Buy
BM	6.81	4.16	Fail	37%	No Buy
BN	6.81	5.68	Pass	15%	No Buy
BO	7.57	8.33	Fail	81%	Buy
BP	5.68	5.3	Pass	17%	No Buy

Source: Mowris 2010 [7]

Flow rates and consumer survey results for CEC PIER hand held models are shown in **Table 7**. Ten percent of models received a “no-buy” rating, and 20 percent passed the flow rate test. Fifty percent of efficient models (2 out of 4) passed the flow rate test. All efficient models received a “buy” rating, and only 1 out of 6 standard models received a “buy” rating. All models passed consumer force and coverage ratings, while 90 percent passed force and coverage tests.

Table 7. Flow Rates and Consumer Survey Results for CEC PIER Hand Held Models

Showerhead Model	Rated Flow @ 550 kPa LPM	Tested Flow @ 550 kPa LPM	Pass Min or Max Flow Rate Test Criteria	CEC PIER Consumer Satisfaction	CEC PIER Consumer "Buy" or "No Buy" Rating
HHA	5.68	2.46	Fail	62%	Buy
HHB	5.68	4.54	Pass	73%	Buy
HHC	7.57	8.52	Fail	83%	Buy
HHD	9.46	8.9	Fail	42%	No Buy
HHE	5.68	5.68	Pass	52%	Buy
HHF	9.46	12.68	Fail	50%	Buy
HHG	9.46	11.55	Fail	60%	Buy
HHH	9.46	11.55	Fail	56%	Buy
HHI	9.46	12.49	Fail	75%	Buy
HHJ	9.46	10.6	Fail	73%	Buy

Source: Mowris 2010 [7]

The CEC PIER model "no buy" rating is correlated to rinse time to remove hair conditioner in **Figure 2**. The polynomial curve fit has a 0.705 R-squared coefficient indicating 70.5% of the variation in the "no-buy" response variable is correlated to the rinse time variable.

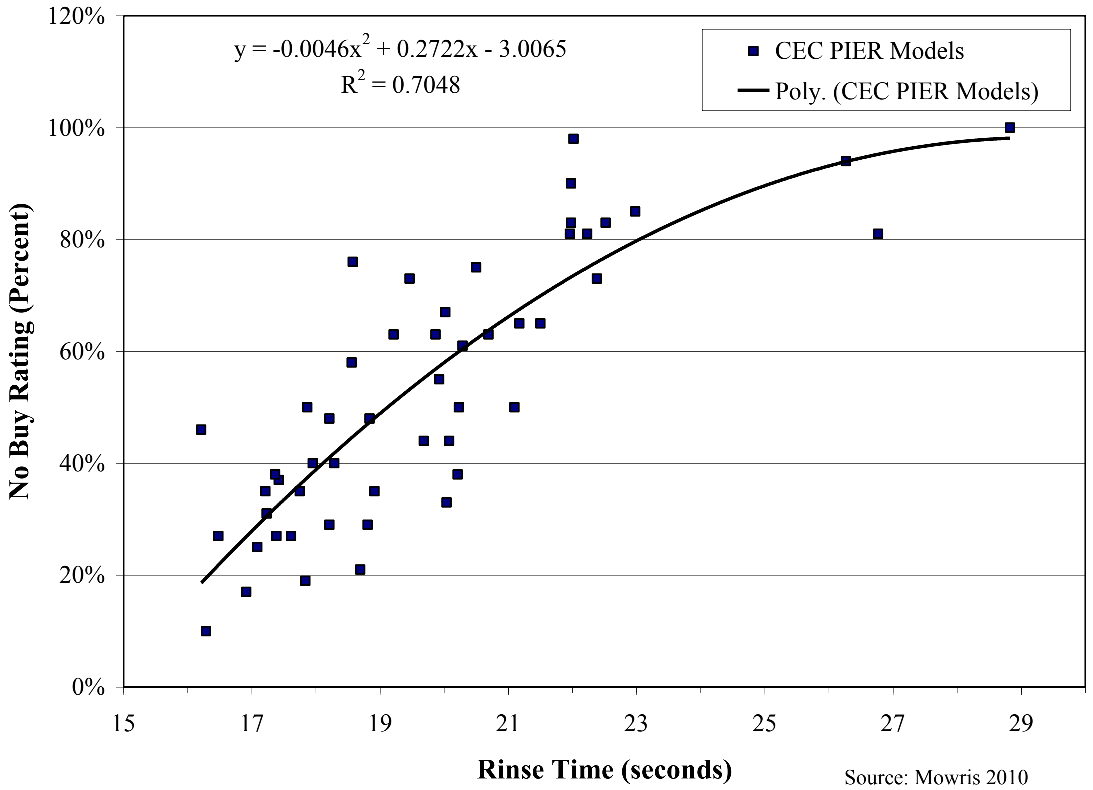


Figure 2. No Buy Rating versus Rinse Time for RMA CEC PIER Models

The results shown in **Tables 5**, **6**, and **7** indicate a relationship between tested flow rates and consumer satisfaction, i.e., higher flow rates yield higher satisfaction. However, there are a number of exceptions such as models K, AO, AU, BD, BH, HHB, and HHE with low flow rates of 5.68 to 6.81 lpm, "Pass" minimum or maximum flow rate test criteria, and "Buy" consumer ratings. More than half (23) of all 41 models have a flow rate of 6.81 or higher. This indicates that it is possible to design showerheads to fulfill both water-efficiency criteria as well as consumer satisfaction criteria. The successful low flow designs use innovative pressure compensating flow technologies and spray designs that are becoming more popular as manufacturers compete for WaterSense® labels and market share in the emerging “green” showerhead market.

Discussion

This study found a strong correlation between laboratory tests and consumer satisfaction survey results for the flow rate criteria where 64 to 77 percent of the WaterSense® showerheads failed the flow rate criteria and 59 to 64 percent of the same showerheads received a “no-buy” rating from the consumer satisfaction survey. There is less correlation between the laboratory tests and consumer satisfaction survey results for the WaterSense® force and coverage criteria. For the force criteria 4.5 to 22.7 percent of the 22 showerheads failed the laboratory tests while 36 percent of the same showerheads failed the consumer satisfaction force criteria. For the coverage criteria 9 to 18 percent of the 22 showerheads failed the laboratory tests while 27 to 41 percent of the showerheads failed the consumer satisfaction coverage criteria. Laboratory test results of 41 fixed showerheads correlate to consumer satisfaction survey results for flow rate but not for force or coverage. Laboratory test results of 10 hand-held showerheads do not correlate to consumer satisfaction survey results with respect to flow rate, force, or coverage primarily due to 60 percent of hand held models being non-compliant and providing higher maximum flow rates than the manufacturer specified at 550 kPa.

Approximately 64 to 77 percent of the showerheads tested in this study do not meet the WaterSense® specification for flow rate, force, or coverage. One reason why so many showerheads fail the flow rate criteria could be the lack of government-required third-party verification testing of maximum allowable flow rates. California Green Building Standards recommend a flow rate lower than 9.46 lpm at 550 kPa flowing pressure. Lowering the California showerhead flow rate standard would put pressure on manufactures to design and manufacture more water-efficient shower heads. The voluntary WaterSense® specification might not put the same pressure on manufactures to accelerate development and diffusion of more water-efficient showerheads into the market.

Conclusions

Based on a survey of 25 manufacturers representing 80 to 90 percent of showerheads sold in the US, 96 percent support the voluntary WaterSense® showerhead specification. Eighty three percent of manufacturers sell efficient showerheads with rated flow rates less than 9.46 lpm at 550 kPa and the average manufacturer offers 5 efficient models. The average retail cost for water saving showerheads is 26 percent less than conventional showerheads. Only one manufacturer reported receiving complaints (for another manufacturer valve) about thermal shock with their showerhead rated at less than 9.46 lpm at 550 kPa.

This study found a strong correlation between laboratory tests and consumer satisfaction survey results for the flow rate criteria where 64 to 77 percent of the WaterSense® showerheads failed the flow rate criteria and 59 to 64 percent of the same showerheads received a “no-buy” rating from the consumer satisfaction survey. There is less correlation between laboratory tests and consumer satisfaction survey results for the WaterSense® force and coverage criteria. Laboratory test results of 41 fixed showerheads correlate to consumer satisfaction survey results for flow rate but not for force or coverage. Laboratory test results of 10 hand-held showerheads do not correlate to consumer satisfaction survey results with respect to flow rate, force, or coverage primarily due to 80 percent of hand held models being non-compliant providing higher flow rates than the manufacturer specified at 550 kPa.

Approximately 64 to 77 percent of the showerheads tested in this study do not meet the WaterSense® specification for flow rate, force, or coverage. One reason why so many showerheads fail the flow rate criteria could be the lack of government required third-party verification testing of maximum allowable flow rates. Based on this finding, this study does not recommend that California adopt the lower flow rate standard specified in the California Green Building Standards. Instead the study findings support the voluntary EPA WaterSense® showerhead specification of 7.6 lpm at 550 kPa flowing pressure to give manufacturers time to design more efficient showerheads.

Test results indicate a relationship between tested flow rates and consumer satisfaction, i.e., higher flow rates yield higher satisfaction. However, seven models have low flow rates of 5.68 to 6.81 lpm, "pass" minimum or maximum flow rate test criteria, and "buy" consumer ratings. More than half (23) of all 41 models have a flow rate of 6.81 or higher. This indicates that it is possible to design showerheads in a way that fulfills both water-efficiency criteria as well as consumer satisfaction criteria. These efficient low flow WaterSense® showerheads use innovative spray designs and pressure compensating flow technologies. Annual savings from improved showerhead standards and labels are estimated at 245 billion liters of water, 19.83 PJ, 3,066 GWh, 3.265 million tonnes of carbon dioxide, and $600 million (USD) per year.

References

[1] Biermayer, P. 2005. Trends in Shower Design and Their Effect on Energy and Water Use. Lawrence Berkeley National Laboratory. In Proceedings of 2006 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C..

[2] American Society of Mechanical Engineers (ASME) A112.18.1/CSA-B125.1-1992/2005. New York, NY: Available online: http://files.asme.org/Catalog/Codes/PrintBook/14122.pdf.

[3] American Society of Sanitary Engineers (ASSE) 10162 or ASME A112.18.1/CSA B125.1.

[4] California Green Building Standards Code (CGBSC). 2010. Chapter 4, Section 4.303 Indoor Water Use, Table 4.303.2 Fixture Flow Rates, Maximum flow rate at 20% reduction or 7.46 lpm @ 550 kPa. Water conservation (plumbing) provisions will take effect in the California Building/Residential Codes on July 7, 2011. http://www.bsc.ca.gov/default.htm.

[5] DOE 1998, Office of Energy Efficiency and Renewable Energy, 10 CFR Part 430, Energy Conservation Program for Consumer Products: Test Procedures and Certification and Enforcement Requirements for Plumbing Products; and Certification and Enforcement Requirements for Residential Appliances; Final Rule., March 18, 1998, section 430.32, p. 13317 of the Federal Register.

[6] Hotel and Motel Management (HMM). 2004. Holiday Inn Express Hits the Showers. http://www.hotelmotel.com/hotelmotel/article/articleDetail.jsp?id=126192, Oct. 1, 2004.

[7] Mowris, R., Woody, B. 2010. Development of New Testing Protocols for Measuring the Performance of Showerheads. Prepared for California Energy Commission Public Interest Energy Research Program. Sacramento, Calif.: California Energy Commission.

[8] Plumbing & Mechanical Magazine. 2002. Available online: www.pmmag.com. June 6, 2002.

[10] Tanner, S., Remedios, S. 2009. WaterSense®: A consensus-based, common sense approach for high-efficiency Showerheads, February 2009. Northbrook, IL.: Plumbing Engineer.

[11] United States Environmental Protection Agency (USEPA). 2010. WaterSense® Specification for Showerheads. Washington, DC.: US Environmental Protection Agency. Available online: http://www.epa.gov/watersense/docs/showerheads_finalspec508.pdf

[12] Wagoner, K. 2008. Showerhead User Satisfaction Study. Prepared for USEPA and ASME/CSA Joint Harmonization Task Force. Chantilly, VA.: Eastern Research Group (ERG).\

Circulators - from voluntary A-G labelling to legislation in EU

Niels Bidstrup

Chief Engineer, Ph. D., GRUNDFOS Management A/S

Abstract

An estimated 140 million circulator pumps are installed in the 27 countries of EU (EU27) today and consume 50 TWh per year. High efficiency circulators saves up to 80% electrical energy compared to standards circulators. This is achieved by using high efficiency permanent magnet motors and speed control.

To increase market share of circulators with higher efficiency the seven level A-G labelling scheme was developed for standalone circulators used in heating systems. The labelling scheme came in force in March 2005 and is controlled by a voluntary industry commitment managed by Europump. The labeling scheme has implied a significant market transformation towards circulators with higher efficiency.

This market transformation is about to be accelerated and have a considerable higher impact when the A-G labelling turns into legislation via the framework directive for the setting of eco-design requirements for energy using products (EuP directive). The Commission Regulation (EC) 641/2009 implements the EuP Directive by specifying ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products. The ecodesign requirements will imply that only circulators comparable with the current A-labelled are allowed after 2013 and only the best 30% of the A-labelled circulators sold today are allowed after 2015. The scope has been broadened significantly in the regulation, which means that also circulators used in the secondary circuit of cooling distribution systems and circulators integrated in i.e boilers, solar systems heat pumps etc. are comprised. The estimated energy saving potential in EU27 is 23 TWh per year in 2020, with a reduction of 11 million tonnes of CO2 per year. This paper describes the market transformation due to the A-G labeling and the future legislation and the implications for the industry and users

Introduction

The path from A-G labelling to EU legislation of circulators is quite long (see figure 1 and figure 2). It started in 1999 by a SAVE II study funded by the European commission [1] where facts about installed base, energy consumption and possibly energy savings were documented.

Based on these facts and an increasing awareness of the energy consumption and possible savings achievable with circulators in Europe, Europump decided to set up a classification scheme for circulators which enabled circulator manufacturers to rate their circulators according to energy efficiency. A methodology to calculate an Energy Efficiency Index (EEI) for circulators was developed and mapped into the A-G classes [2], [3].

The A-G labelling of circulators came in force in March 2005 and is controlled by a voluntary industry commitment, which is managed by Europump [4]. Today nearly all circulator manufacturers who place circulators on the market in EU have signed the commitment, which means that nearly all comprised circulators in EU are labelled with the EU A-G energy label.

In 2006 circulators was chosen as a product group, which should undergo a preparatory study as a part of lot 11 in relation to the EuP directive [5]. The preparatory study estimated the total environmental impact of circulators and defines potential implementing measures for circulators [6]. The proposed implementing measures were based on the classification scheme developed by Europump.

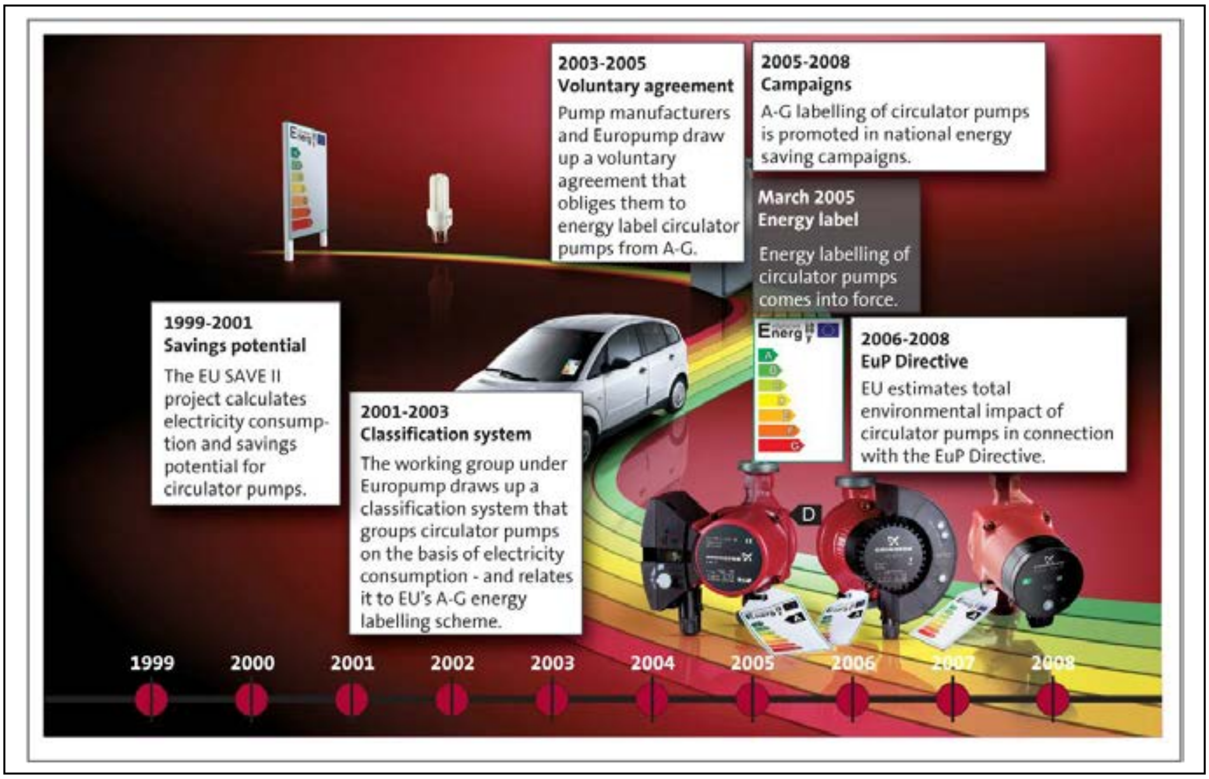


Figure 1 The path from A-G labelling to EU legislation 1999-2008

After the preparatory study, the calculation method was updated to reflect the state of the art circulators on the market in 2009 and energy efficiency requirements based on EEI was set up in Commission regulation 641/2009 (EC) [7], which was adopted in July 2009

Figure 2 The path from A-G labelling to EU legislation 2009-2017

A-G labelling of circulators

The current A-G labelling scheme comprises all circulators for heating systems, which fulfill all conditions below

- Standalone (not an integral part of a boiler)
- Pump and motor integrated
- Wet runner (glandless)
- Centrifugal pumping
- P1<2500 W

Standalone circulators with pump and motor integrated are circulators, which are sold as a separate product and not as an integral part of, for example, a boiler. Wet runner means that the rotor is running in the pumped fluid. Only circulators with a power input P1<2500 [W] (for every head on double pumps) and based on centrifugal pumping principle are comprised.

Energy efficiency index

The A-G labeling scheme is based on a classification scheme set up by Europump. The key element of the classification scheme is the Energy Efficiency Index (EEI) which is calculated as

$$EEI = \frac{P_{L,avg}}{P_{ref}} \quad [-] \qquad \text{(eq 1.0)}$$

Where $P_{L,avg}$ is the weighted average compensated power input based on a yearly load profile and compensated for control error.

P_{ref} is the reference power input of a state of the art non-controlled circulator. The efficiency of a circulator is dependent on size. This means that the relation between rated power input and rated hydraulic power (P_{hyd}) isn't constant, which would imply that also the EEI was dependent of size. This dependency was eliminated by making P_{ref} a function of P_{hyd}.

$$P_{ref} = \quad 2.21 \cdot P_{hyd} + 55 \cdot \left(1 - e^{-0.39 \cdot P_{hyd}}\right)[W]$$

With this modification state of the art non-controlled circulators have the same rating independent of size.

State of the art non-controlled circulators will have a energy efficiency index just below EEI=1.0. Circulators with improved efficiency will have a rating of EEI< 1.0. Circulators with poorer efficiency are rated EEI>1.0.

The EEI was mapped into the A-G range as shown in Table 1.

Class	Energy Efficiency Index
A	EEI < 0.40
B	0.40 ≤ EEI < 0.60
C	0.60 ≤ EEI < 0.80
D	0.80 ≤ EEI < 1.00
E	1.00 ≤ EEI < 1.20
F	1.20 ≤ EEI < 1.40
G	1.40 ≤ EEI

Table 1: Mapping between EEI and A-G ratings

This mapping implies that by the introduction of the A-G labelling scheme in 2005 a state of the art non-controlled circulator would be "D" rated.

Market transformation due to A-G labeling

By signing the industry agreement manufacturers committed themselves to do their utmost to label all circulators. They also committed themselves to submit data to Europump about the A-G distribution of sold products and estimated market shares of circulators in scope. This enables Europump to monitor and report on the market transformation due to the labelling scheme [8].

The market transformation from 2004 to 2009 is shown in figure 3. The first year of the reporting is 2004 and serves as the base year for the monitoring process. This is the year before the labelling scheme came in force and hence shows the market situation before the introduction of the A-G labeling of circulators. The monitoring process is based on all comprised circulators on the market from manufacturers who have signed the commitment, whether the circulators are labelled or not. This enables the calculation of A-G distribution of comprised circulators on the market since 2004.

Since the introduction of the A-G labelling of circulators in 2005 a significant market transformation towards circulators with higher efficiency has taken place. The graph clearly shows a market transformation from class "D" to class "B". This transformation is due to a pull effect from the market, but also due to a push effect from some manufactures who have improved their standard circulators from "D" to "B".

The graph also shows that the sale of high efficiency (A-rated) circulators have increased from 1.6 % to 18.9 %

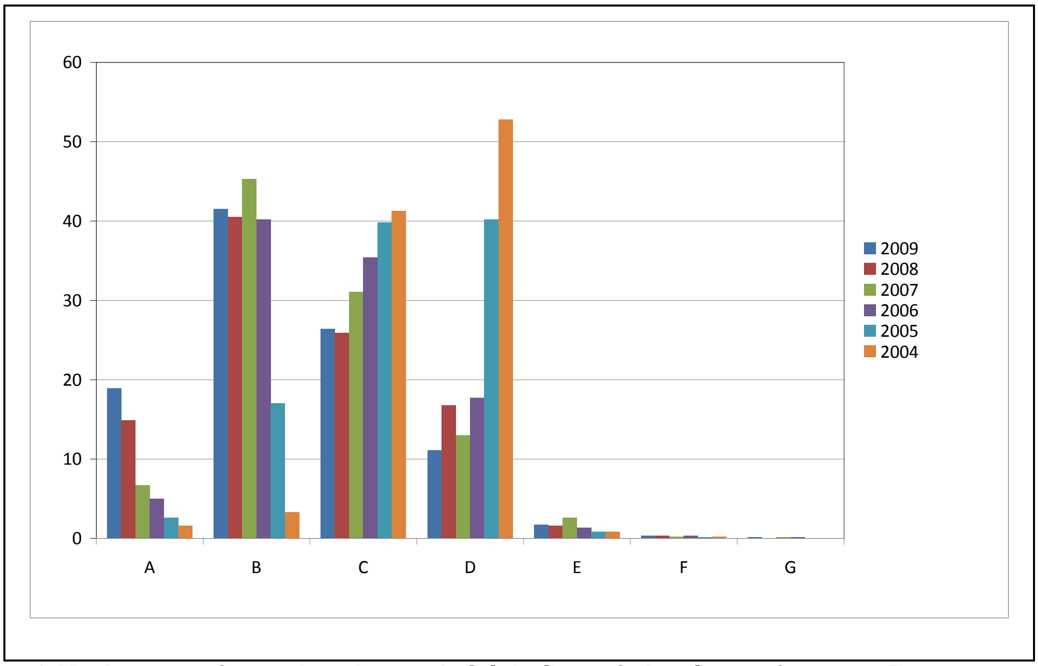


Figure 3 Market transformation due to A-G labeling of circulators (source: Europump , Briefing document regarding the INDUSTRY COMMITMENT [8], page 4)

Despite this significant market transformation Europump does not believe that the voluntary industry commitment will imply a full market transformation to high efficiency circulators in EU and welcomes legislative measures which follow up on the industry commitment.

EuP Directive

EU legislation on circulators is introduced via Directive 2005/32/EC – framework for the setting of eco-design requirements for energy using products [5] also referred to as the EuP directive. A recast of the directive was adopted in 2009 (Directive 2009/125 (EC)), where the scope was amended to cover energy related products ErP's. This has no impact on the scope and requirements for EuP's.

The overall objective with the EuP directive is to

- Reduce the environmental impact of energy using products
- Contributing to sustainable development
- Enhance security of energy supply

The scope of the EuP directive is

- All energy using products except vehicles for transport of persons and goods
- Sales volume of more than 200.000 units a year within the EU
- Products with a significant environmental impact and potential for reductions
- All energy sources

The EuP directive enables the European Commission to set implementing measures to reduce the eco-impact of products.

Product manufacturers ensure and declare that a product complies with the ecodesign requirements by affixing a CE mark and issuing an EC declaration of conformity for the product. Products in scope that do not comply with these ecodesign requirements must not be CE marked and are prohibited from being placed on the market or put into service within the EU.

Circulators in buildings were identified as being relevant for an eco-impact evaluation in relation to the EuP directive. The eco-impact evaluation of circulators was done by AEA technology in UK [6]. The

European Association of Pump Manufacturers (Europump), which was a stakeholder in the eco-impact evaluation process for circulators, established a joint working group to coordinate inputs from circulator pump manufactures.

Ecodesign requirements for Circulators in EU

The EuP directive is a framework directive which means that the actual ecodesign requirements are set out in a commission regulation which implements the directive. The ecodesign requirements for circulators in EU are set out in Commission regulation 641/2009 (EC) [7].

The eco-impact evaluation revealed that the environmental impact of a circulator is dominated by the use-phase electricity consumption. Due to that the eco-design requirements set out in commission regulation 641/2009 (EC) is focused on energy efficiency requirements.

Recalibration of methodology for calculating EEI

The energy efficiency requirements in the commission regulation are based on the EEI methodology developed by Europump.

Since 2005 new high efficiency small circulators have emerged on the market, which have changed the state the art for this circulator size. This means that the reference power input function (P_{ref}) need to be updated before applying new threshold values.

Based on a data collection from circulators manufacturers the P_{ref} function was updated by Darmstadt University [9]. The updated function is

$$P_{ref} = 1.7 \cdot P_{hyd} + 17 \cdot \left(1 - e^{-0.3 \cdot P_{hyd}}\right), \quad 1\mathrm{W} \le \mathrm{P_{hyd}} \le 2500\mathrm{W}$$

To keep the relation to the A-G labelling a calibration factor was introduced to the EEI calculation, which means that the EEI now is calculated as

$$EEI = \frac{P_{L,avg}}{P_{ref}} \cdot C_{20\%} \quad [-]$$

where $C_{20\%}$ =0,49 and is chosen such that 20% the circulators on the market will be below EEI=0.20.

Energy efficiency requirements

The actual energy efficiency requirements set out in commission regulation 641/2009 (EC) is

1. From 1 January 2013, glandless standalone circulators, with the exception of those specifically designed for primary circuits of thermal solar systems and of heat pumps, shall have an energy efficiency index (EEI) of not more than 0,27

2. From 1 August 2015, glandless standalone circulators and glandless circulators integrated in products shall have an energy efficiency index (EEI) of not more than 0,23

The energy efficiency index of circulators shall be indicated on the name plate and packaging of the product and in the technical documentation as follows: 'EEI ≤ 0,[xx]';

Further more a bench mark level for the most efficient circulators is defined as EEI ≤ 0.20. The bench mark level information shall be visibly displayed on freely accessible websites of the circulator manufacturers.

These ecodesign requirements will imply that only circulators with an efficiency comparable with the current A-labelled circulators are allowed after 2013 and only the best 30% of the A-labelled circulators sold today are allowed after 2015.

Circulators in scope of commission regulation

The comprised circulators in the industry commitment were glandless standalone circulators for heating systems. The scope in the regulation has been broadened significantly. A circulator is defines as

- ‘circulator’ means an impeller pump which has the rated hydraulic output power of between 1 W and 2500 W and is designed for use in heating systems or in secondary circuits of cooling distribution systems;

This means that the scope of applications have been broadened to cover the secondary circuit of cooling distribution systems.

Further more the comprised circulators includes circulators integrated in products. The definition of a products is

- ‘product’ means an appliance that generates and/or transfers heat;

This means that circulators integrated in i.e. boilers, solar systems heat pumps etc. are comprised

Figure 4 shows the main difference between standalone and product integrated circulators. Standalone circulators are designed to be sold and installed as a separate product. Products integrated circulators are integrated and sold as a part of another product.

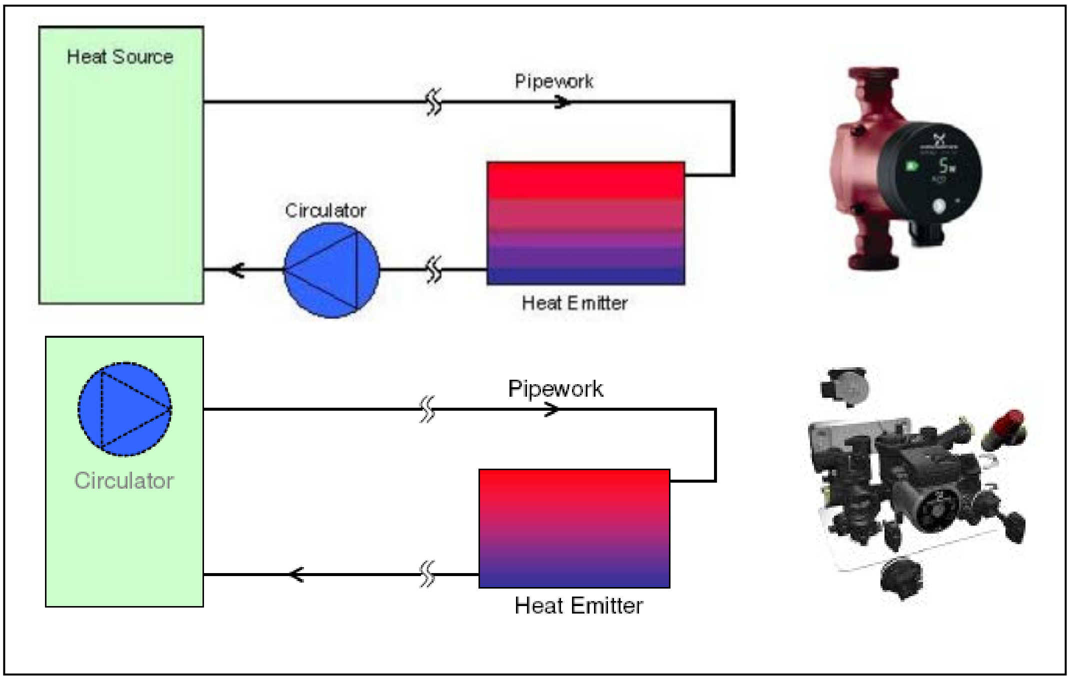


Figure 4 Glandless standalone and product integrated circulators

Because of the variety of integrated circulators both in term of design and applications the methodology for calculating the energy efficiency index for product integrated circulators will be reviewed before January 2012.

Harmonized EN standards

The compliance and verification of compliance with the requirements of the commission regulation will be based on standardized measurement procedures.

The European Committee for Standardization (CEN) has been mandated to develop these standardized measurement procedures. A pre-standard is sent out in enquiry which describes the procedures for measurement and calculation of hydraulic power, power consumption, and energy efficiency index of circulators in scope of Commission regulations (EC) 641/2009

The standard consists of three parts (prEN 16297-1 [10], prEN 16297-2 [11], prEN 16297-3 [12]), which concerns the general requirement, standalone circulators and product integrated circulators respectively

- Pumps — Rotodynamic pumps – Glandless circulators — Part 1: General requirements and procedures for testing and calculation of energy efficiency index (EEI)
- Pumps — Rotodynamic pumps – Glandless circulators — Part 2: Calculation of energy efficiency index (EEI) for standalone circulators
- Pumps — Rotodynamic pumps – Glandless circulators — Part 3: Energy efficiency index (EEI) for circulators integrated in products

The following definitions can be used as a guideline to identify which part of the standard to apply:

Standalone circulator means a circulator designed to operate independently from the product and should be tested and calculated in accordance with Part 2 of this standard.

Circulator integrated in a product means a circulator designed to operate dependently of the products and should be tested and calculated in accordance with Part 3 of this standard. A circulator is considered to be operated dependently if it carries at least one of the design details listed in the Table 2.

<table>
<tr><th>Design</th><th>Details</th><th>Examples
(non exhaustive list)</th></tr>
<tr><td rowspan="2">Pump housing</td><td rowspan="2">Designed to be mounted and used inside a product</td><td>Housings designed for use inside products e.g. with clip connections, with back panel connection or plate heat exchanger connections.</td></tr>
<tr><td>Housings integrating electrically or thermally driven valve functions</td></tr>
<tr><td>Control</td><td>Designed to be speed controlled by the product</td><td>Circulators with product specific control signal interfaces</td></tr>
<tr><td rowspan="2">Safety measures</td><td>Designed with safety features not suitable for stand alone operation</td><td>Product takes over safety features (ISO IP classes)</td></tr>
<tr><td>Circulator is a defined part of product approval or product CE marking</td><td>Circulator is part of the component list of product approval or product CE marking</td></tr>
</table>

Table 2 Different design details for product integrated circulators

Estimated energy consumption and savings due to EU legislation

Figure 5 shows the reduction in annual energy consumption of small circulator pumps. Since 1999 the annual energy consumption of circulators have been reduced significantly which implies saving up to 80% compared to the standard circulator in 1999. These energy savings are achieved by changing the induction motor to high efficiency permanent magnet motors and applying speed control [13].

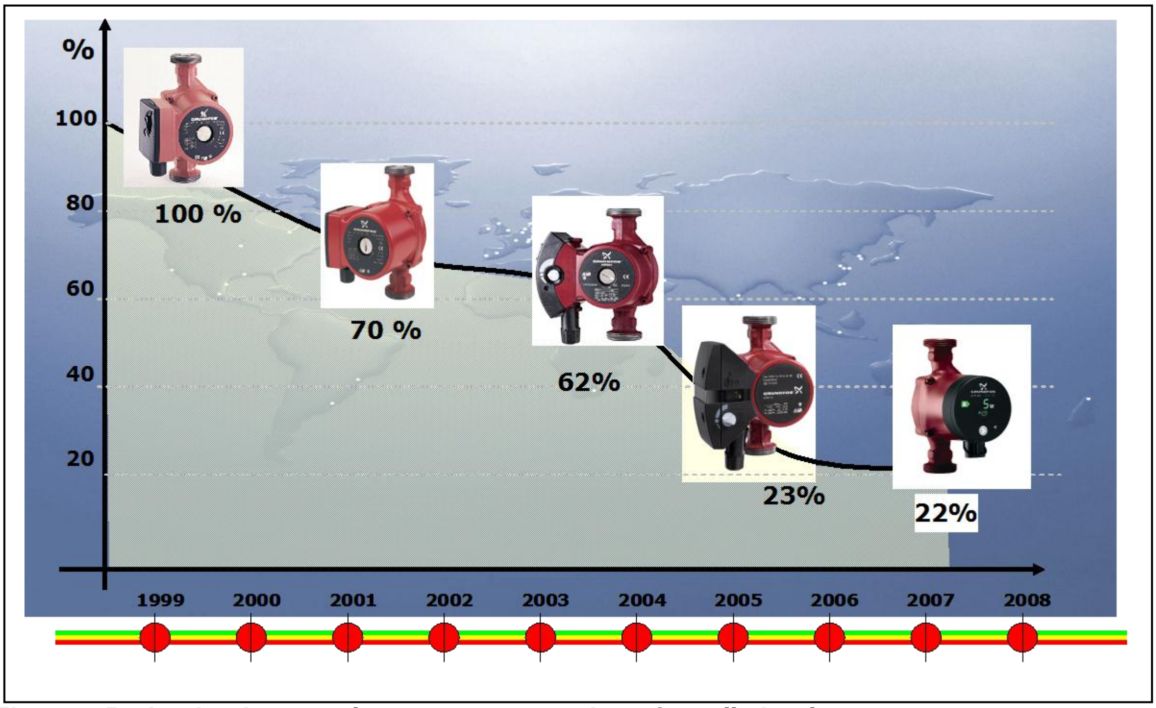


Figure 5 Reduction in annual energy consumption of small circulator pumps

Due to the commission regulation only the circulators on the far right on the figure is allowed to be place on the market after 2013.

Figure 6 shows the estimated energy consumption, saving potentials and the related CO_2 emissions today and in 2020 due to this legislation.

Today an estimated installed base of 140 millions circulators in EU27 consumes 50 TWh per year. Without this legislation the annual energy consumption would increase to 55 TWh per year in 2020

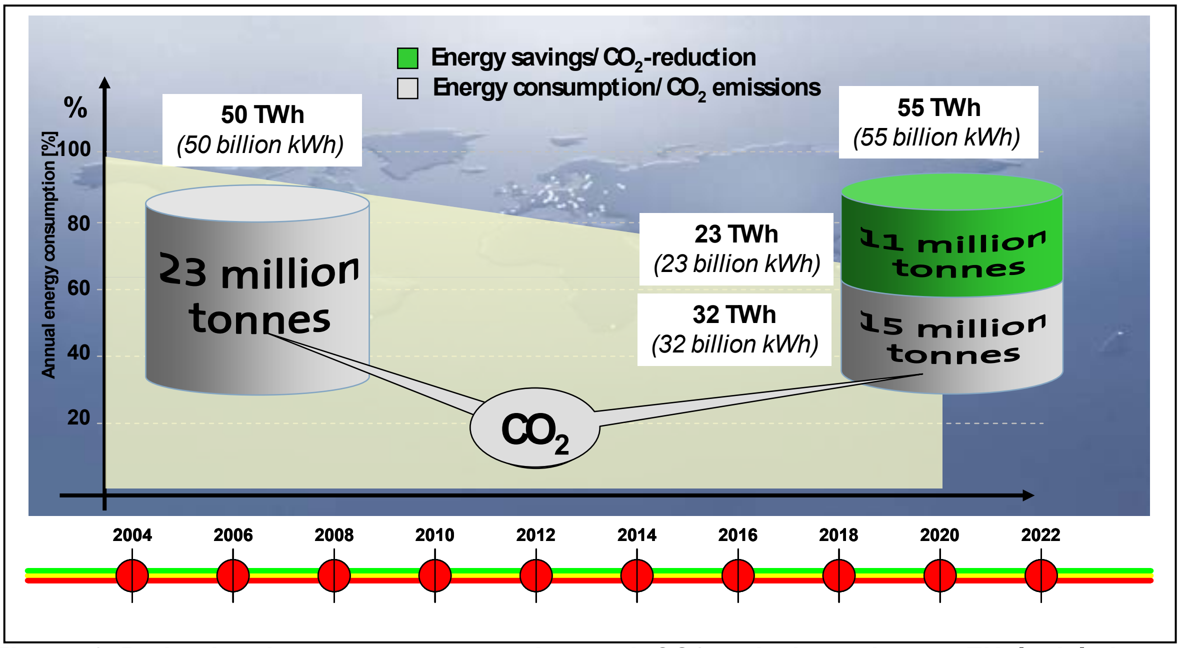


Figure 6 Reduction in energy consumption and CO2-emissions due to EU legislation on circulator

The energy efficiency requirements set out in Commission regulation 641/2209 will decrease the energy comsumption in EU27 to 32 TWh per year in 2020, which means energy savings of 23 TWh per year in EU27 in 2020, with a reduction of 11 million tonnes CO_2 per year [14].

Conclusions

A classification scheme developed by Europump made it possible to rate circulators according to their efficiency. The classification scheme formed the basis for an A-G labeling of circulators and later an energy efficiency requirement via the EuP directive

Circulators are a mass produced product. The preparatory study showed an annual market of 14 millions circulators in EU27. This can be split into 5.5 millions small standalone circulators; 1.0 million large standalone circulators and 7.5 million product integrated circulators.

The ecodesign requirements will imply that only circulators with an efficiency comparable with the current A-labelled are allowed to be placed on the market after 2013 and only the best 30% of the current A-labelled circulators can be placed on the market after 2015

The reporting from Europump shows that 18.9% of standalone circulators sold on the market today are high efficiency circulators (A-rated). This is a significant market transformation but 80% of the standalone circulators still need to be converted in 2013. Due to the fact that product integrated circulators are not in scope of the voluntary industry commitment and the share of high efficiency circulators in this segment is lower means that a market of 12-13 million circulators a year need to be converted before 2015.

At the moment circulator manufacturers are preparing for that. The industry will be ready but it requires massive investment in development and production facilities.

These requirements will lead to savings of 23 TWh in EU27 in 2020 with a reduction of 11 million tonnes CO_2 per year. This is a significant environmental impact and also a benefit for the end-user who can save up to 10% on the electricity bill.

References

[1] Bidstrup, N., van Elburg, M. and Lane, K., Promotion of Energy Effi-ciency in Circulation Pumps especially in Domestic Heating Systems, Study under SAVE II programme, June 2001.

[2] Bidstrup, N., Hunnekuhl, G., Heinrich, H. and Andersen, T., Classification of Circulators, Europump report, January 2003

[3] Bidstrup et al. Classification of circulators, Proc. of the EEDAL'03 (Turin, Italy 2003)

[4] Europump, INDUSTRY COMMITMENT – To improve the energy performance of stand-alone circulators through the setting-up of a classification scheme in relation to energy labelling, 2005

[5] Directive 2005/32/EC of the European parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products. Can be downloaded at: http://europa.eu.int/eur-lex/

[6] Falkner, H., EUP Lot 11: Circulators in buildings, AEA report to European Commission, Issue No. 4, Ed. number 02287, February 2008; www.ecomotors.org

[7] European Commission. Commission regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products. Can be downloaded at: http://europa.eu.int/eur-lex/

[8] Europump, Briefing document regarding the INDUSTRY COMMITMENT – To improve the energy performance of stand-alone circulators through the setting-up of a classification scheme in relation to energy, MM 2010 Can be downloaded at: http://europump.org/

[9] Ludwig, G., Roth, M., Results of Circulator Labelling Revision, Technicshe Universität Darmstadt, December 2008

[10] prEN 16297-1 Pumps — Rotodynamic pumps - Circulation pumps having a rated power input not exceeding 200 W for heating installations and domestic hot water instal-lations — Part 1: General requirements, testing, marking

[11] prEN 16297-2 Pumps — Rotodynamic pumps – Glandless circulators — Part 2: Calculation of energy efficiency index (EEI) for standalone circulators

[12] prEN 16297-3 Pumps — Rotodynamic pumps – Glandless circulators — Part 3: Energy efficiency index (EEI) for circulators integrated in products

[13] Bidstrup, N. , A New Generation of Intelligent Electronically Controlled Circulator Pumps, 2nd International conference on Improving Electricity Efficiency in Commercial Buildings (IEECB), Nice 2002

[14] European Commission. Commission staff working document. Accompanying document to the proposal fo a commission regulation implementing Directive 2005/32/EC with regard to Ecodesign requirements for circulators – Full Impact Assessment. Can be downloaded at: http://europa.eu.int/eur-lex/

Carbon Fiber electric Heating Systems

Mirko Tonello and Maurizio Nespoli

Thermo Easy, Italy

Introduction: Directions given by the directives on emissions and renewable energy

In the past years, starting with the Kyoto Protocol, both national and international legislation many regulations concerning renewable energy has been introduced. In particular, the European Parliament has issued guidelines which set binding targets for EU member states. The first European directive in this regard is Directive 2001/77/EC, adopted in 2001, which promotes the production of electricity from renewable sources to be able to meet the requirements of the Kyoto Protocol. The following year came into force the 2002/91/EC Directive that, even if it do not refers directly at the use of renewable sources, provides important provisions on building energy performance and therefore on a related topic, the use of renewable energy. In 2006 was issued Directive 2006/32/EC on energy end-use efficiency and energy services: it is important because it defines the way of energy management for a better use of economic resources available.

In 2009 the 2009/28/EC Directive was released: it decreed the repeal of Directive 2001/77/EC and is responsible for promoting the use of energy from renewable sources. The following year the 2010/31/UE Directive referring at Buildings Energy Performance was finally adopted.
All these directives are promoting the installation and use of systems that use renewable energy and the improving of the buildings energetic efficiency, to be able to achieve some goals, such as:

- Reduction of the global emissions of greenhouse effect gases with 20% below the 1990 levels until 2020;
- 20% reduction of the energy consumption in European Union until 2020;
- Cover at least 20% of European Union energy demand by using energy from renewable sources.

To fulfill the requirements of the European and national regulations, it becomes ever more pressing obligation to design and build energy efficient buildings in all their components, from building envelope to technological systems installed.

Thanks to the great strides made in this field, the primary energy demand for heating in new buildings and buildings subject to upgrading the energy efficiency, is very low, which leads to a significant lowering of the operating costs of the system and emissions of CO_2 in the atmosphere, in compliance with the requirements of the legislation in force. With expenditure, still low due to the system operation, becomes important to optimally manage the financial resources for the installation and construction of the systems.

Need to improve the buildings constructions methods

First of all the structure of the building must be able to limit the heat dispersion- heat loss from the inside.
A crucial help in this regard is given by the insulation materials that are more and more used in building construction.

A good thermal insulation ensures:

- Heat losses restraint;
- Comfortale indoor climate
- reduction heating and cooling costs;
- reduction of “thermal bridges”;
- does not lead to construction defects;
- absence of moisture and mould;
- longer lifetime of the building.

Another important aspect concerns the glass surfaces. The introduction of low emissivity windows with specific insulating layer filled with gas between the glass sheets, lead to a great progress in this domain.

For the construction of energy-efficient structures, it is essential to take care of the thermal bridges, real routes for heat loss which affect the good insulation of a building: through various project and constructions methods they can be completely eliminated.

All these factors: adaptation to the requirements of the legislation in force, improving construction techniques, lead to the reality of new buildings which have a heat requirement 4 times smaller than buildings made twenty years ago.

Example :

A house for a single family , built with this methods , with 150m² of surface could have 4500 kWh of consumption .

The use of renewable resources

Recently, there has been an improvement of the mechanisms of energy production. This technical progress has determined a high efficiency development of the plants. In response to the continuous and constant development of the sector, increasingly positive results and realization costs more and more content are prospected. The future does not seem to be able to avoid a gradual spread of this kind of systems, destined to become dominant in a short time.

Subsidies for promoting the systems

During time, many European countries have introduced financial support for person who decides to install on their property, power plant for the production of energy from renewable sources.

This support is offered in several ways: providing a contribution as a percentage of the total cost of the system, or payment for energy produced by applying a standard rate fixed for a certain number of years.

This financial aid positively reflected and still reflects the deployment of alternative energy.

Heating systems

Focusing particularly on heating systems, it is of primary importance to be able to provide the end user with an efficient system without placing an excessive burden on financial resources.

The combination of technological systems to systems that exploit the renewable energy is perhaps the main method to be able to give the end user an efficient and inexpensive system.

Heating system that uses electrical energy combined with a photovoltaic system may be one of these systems .

Given the need for low energy for heating buildings . A pure electric system is increasingly applicable in the new building to save energy

Low energy consumption - search for maximal system efficiency

Once determined the need to design and construct buildings more efficient in terms of heat demand, the attention should be directed to the search of the heating low energy demand systems (up to 4 times lower than the systems related to traditional coal), having following characteristics:

- flexibility and efficiency, capacity of solving the usual problems that may appear in heating systems and to be used in different ways (floor heating, wall/ ceiling heating, radiators, heating panels)
- speed and maximal efficiency
- durability, does not require regular or occasional maintenance;
- quality components, which do not require periodic replacement;
- economic- cost, i.e. costs of purchase, consumption and maintenance are considerably lower than other systems'.

Less expense with the heating system installation leaves the user with a disposable income that may be invested in the installation of a plant for the production of energy from renewable sources.

Carbon fiber characteristics.

Thermal Technology heating system principle is based in exclusivity on using the carbon fiber powered with electricity. In this way the carbon fiber becomes a resistor wich act as a heating element.

For a better understanding of these systems operating mode we provide some brief information about the Carbon Fiber.

Natural carbon can be found in several shapes and composition: organic and inorganic.

The need for its processing appeared in aerospatial industry which was demanding high resistance, low weight and low operating costs materials.
Carbon fiber was discovered in 1879 by Edison, but its industrial production began in 1960, using a technology developed by William Watt for the Royal Aircraft UK.
Carbon fiber appeared in 1960 was manufactured by altering composition of organic substances with a high percentage of Carbon (rayon, olyacrylonitrile, etc.) or some distillation residues resulted from the oil processing. The first are called PAN carbon fibers, the last are called PITCH carbon fiber.
Both carbon fibers are commonly used in applications such as fabrics and films.

The key differences between the two of them are the tensile strenght, specific weight and electrical resistivity.

The carbon fiber used by Thermal Technology are PAN and has the following features:

1. Has a tensile strength equal to that of steel (2500 N/mm2);
2. Has a specific weight of 1.9 g/cm3
3. Has the resistivity of 0,000035 Ωm;

These data are relevant in a comparison with the corresponding values for other materials: for example, copper has a specific weight of 8,9 g/cm3 and an electrical resistivity of 0,000000017 Ωm, meaning 2.058 times less than Carbon Fiber's.

The low value of the Carbon Fiber specific weight has as effect the heat transfer almost instantaneous transfer of heat to the bodies / substances with which it comes into contact.

The above mentioned carbon features gain meaning when we analyze the behavior of different materials on their completion of an electrical current. High resistivity has as consequence an increased thermal (Joule) effect (the amount of heat generated when electric current passes through a given material is inversely proportional to the electrical resistivity of the material in question).

These are the two advantages that determine the high efficiency of carbon fiber as heating element in comparison with other electric heating systems that use traditional resistance: metals or their alloys.

Main system's features of carbon fiber :

- Absence of thermal inertia
- transfers the heat very quickly
- durable
- flexibility
- same efficiency in all conditions of temperature (-40 to +300 ° C)
- no thermal expansion
- does not oxidize

Comparison with Copper heating cable

PHYSICAL PROPERTIES			
	CARBON	**COPPER**	**CONCEPT**
α (°C -1)	-0,0005	0,0043	temperature coefficient
D (Kg/m3)	2260	8920	density
S (m2)	0,0000025	0,0000025	cable section
ρ (Ω*m)	0,000035	0,000000017	resistance

Ce (J/Kg*m)	710	384,4	specific heat

If we start from the law of conservation of energy and that all the electric energy turns into heat, we can state that:

$$Ee = R\ x\ i^2\ x\ t$$

$$Q = m\ x\ Ce\ x\ \Delta T$$

comparing these simple equations:

$$Ee = R\ x\ i^2\ x\ t = m\ x\ Ce\ \ \Delta T = Q$$

And doing a series of mathematical operations we can obtain the following expression:

$$i = \frac{\sqrt[2]{\frac{D \times Ce}{\rho} \times \left(\frac{1}{\alpha}\right) \times ln\left(\frac{\left(\frac{1}{\alpha} - 20\right) + T2}{\left(\frac{1}{\alpha} - 20\right) + T1}\right)}}{\sqrt[2]{t}} \times S$$

With this we can show that: if we fix the T1 and T2 temperatures as initial and final temperatures of an heating system of copper and another one of carbon, we see that, for a length of time, the carbon heating system consumes less intensity than a copper heating system.

<u>The consumed intensity is highly lower for the same length of time.</u>

So if we state the expression following the time:

$$t = \frac{D \times Ce \times S^2}{\rho} \times \frac{1}{i} \times \left(\frac{1}{\alpha}\right) \times ln\left(\frac{\left(\frac{1}{\alpha} - 20\right) + T2}{\left(\frac{1}{\alpha} - 20\right) + T1}\right)$$

If we fix the initial and final temperature, we see that the carbon reaches the wanted temperature shortly.

<u>The required time to reach the wanted temperature is shorter than the other heating system.</u>

On equal temperature terms and conductor section:

- the carbon density is lower than that of copper for 25%
- the carbon specific heat is major than that of copper for 54%
- the carbon resistance is highly major than that of copper, concretely is 2058,82 times major because it is a material of great resistance if compared with copper.

This last characteristic makes the carbon more efficient for heating application compared to the other systems on the market.

The Joule effect is given by a great resistance

For example, for a metre of conductor powered by 10 Ampere:

We know that:

$$R = \rho \times \frac{longitud}{Sección}$$

$$P = R \times I^2$$

Joule Effect

	Resistance (Ω*m)	Intensity	Power (W)
C	14,00000	10	1400
Cu	0,00680	10	0,68

As consequence to the high resistance, on equal intensity are produced more losses for the Joule effect.

And for this reason, thanks to the great thermal transmission capacity and the quickness in dispersing the heat energy produced by the Joule effect, this heating system is a simple solution for the sustainable construction and it respects the ecological aspect.

So to generate 100W with copper, is needed an intensity 45 times higher than with carbon.

Fixing the power

	Power (W)	Resistance (Ω*m)	Intensity
C	100	14,00000	2,67
Cu	100	0,00680	121,27

Heating systems that use the Carbon Fiber

Carbon fiber heating systems are generally based on the radiation principle.

Radiation is a heat exchange system that uses infrared waves as a transfer vector. In fact, two bodies or two objects having different temperatures radiate naturally towards each other and the heat flux goes from the warmer to the colder one. The radiation released by an under floor heating system is transformed into heat in contact with an object, a wall or a person. Infrared waves are absorbed by the solid bodies that turn them into heat energy. This energy is transmitted into the environment, creating, thus, the optimal comfort for the occupants.

Main system's features of carbon fiber heating systems:

- quick and easy installation
- fast heating - absence of inertia
- reduced size
- no maintenance required
- does not produce electromagnetic fields

System flexibility

Due to the carbon fiber physical and mechanical properties, carbon fiber heating system has a high flexibility and it can be integrated into several constructions.

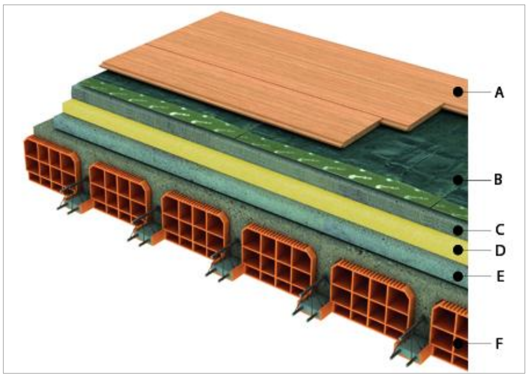
Possible applications are:

- floor
- wall and ceiling
- elements of design
- radiators and radiant panels
- platforms and carpet
- industrial application

Floor applications

The floor heating system uses the principle of radiation and operates at low temperature; it doesn't create air movements, eliminates the temperature differences between areas of the environment, and ensure maximal comfort.

The system was developed to meet various application requirements for both new construction and renovations. Due to the minimal thickness of the system it can be installed in various ambiences. The system also guarantees a temperature difference between floor and ceiling below 2°C. Therefore the curve of temperature distribution is ideal for thermal comfort.

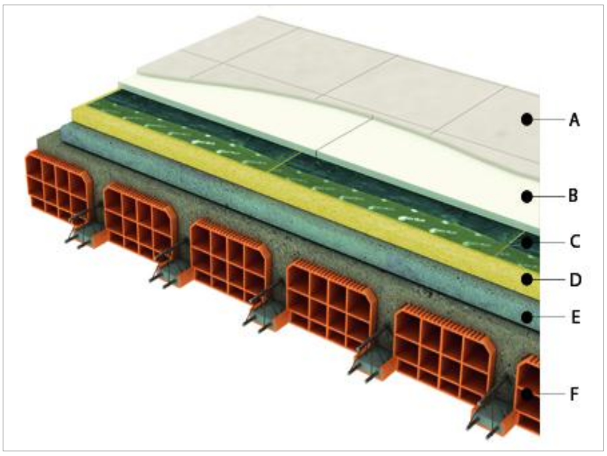


Application of heating element (mat) directly under laminate flooring

A) CERAMIC FLOOR-WOOD

B) HEATING MAT

C) CEMENT SCREED



D) INSULATING PANEL

E) FILLING LAYER

F) FLOOR SLABS

The application of carbon fiber heating element directly under the floor guarantees a very quick heating of the surface. Thus, it is not necessary to heat cement screed, and wait until the room is heated, as it would be necessary longer time comparing to the traditional heating system.

Application of heating element (mat) under dry screed with small thickness

A) CERAMIC FLOOR-WOOD

B) DRY SCREED MADE FROM GYPSUM FIBER PANELS

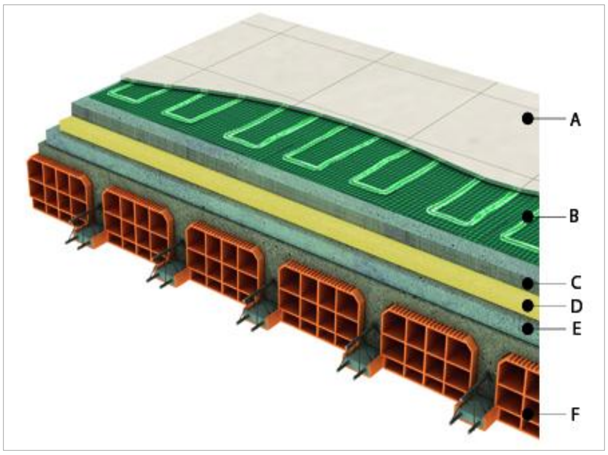
C) HEATING MAT

D) INSULATING PANEL

E) FILLING LAYER

F) FLOOR SLAB

As the previous application, heating of a substrate of reduced thickness with high thermal conductivity allows to reach an operating surface temperature in short time.



Application of heating element (mesh) under ceramic tiles

A) MARBLE-CERAMIC FLOOR

B) HEATING MESH

C) CEMENT SCREED

D) THERMAL INSULATION PANEL

E) FILLING LAYER

F) FLOOR SLAB

Wall/ ceiling applications

Application of a heating element into the wall

The application of the heating element in the wall can be realized as shown in the picture using gypsum fiber panels, or heating elements that can be inserted under plaster or under plasterboards.

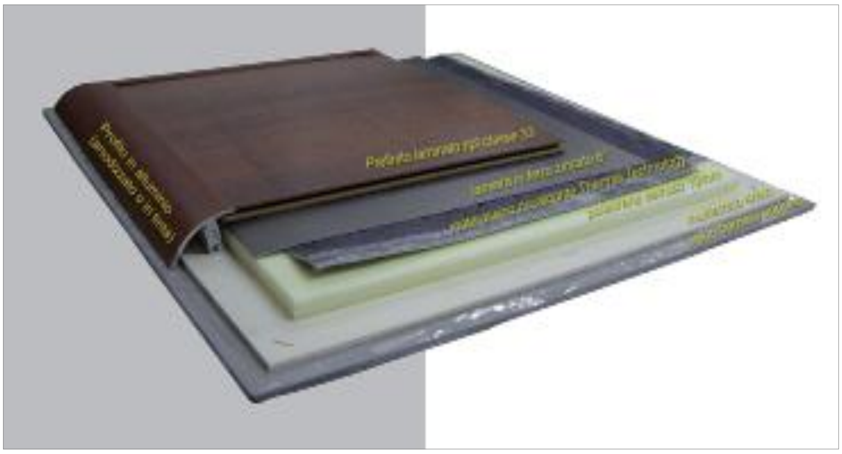
Design elements

Thermal Technology radiators and towel warmers are composed of a carbon fiber heating element that transfers the heat to the radiant plate in the frontal side of radiator. The frontal plate can be manufactured from polished or painted steel, glass or ceramic. There are different models, but all of them heat the environment using two heating principles: the diffuse radiation through the frontal plate and the natural air convection, created through the channel located inside the radiator, thus increasing thermal efficiency.

A common feature of radiators and towel warmers is their small thickness (3 cm – in average), thus the possibility of various installation, in any room, without disturbing the environment and saving a lot of space.

Heating platforms and carpets

These systems are designed to create comfort zones located only where is necessary, functioning only when required, for designed areas and to the desired temperature. Usually, they are installed in environments where is not possible to remove the existing flooring.



Platform structure

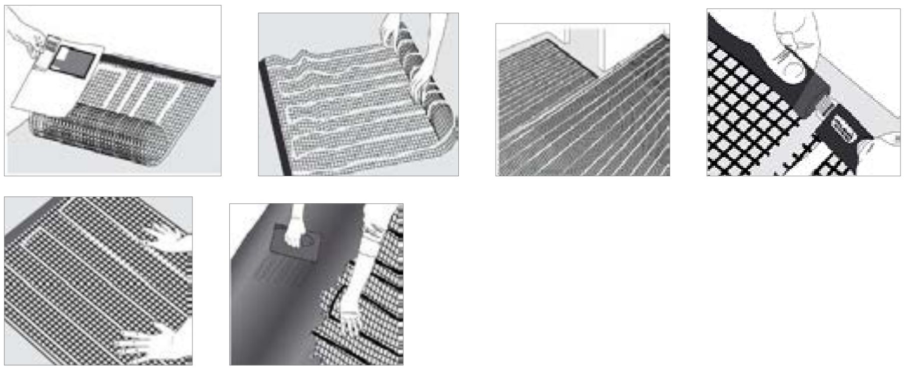
Easy Installation

Thermal Technology systems are easy to install. Particularly, floor heating systems are supplied in two versions:

- modular
- customized

Modular system consists of a various elements, with different sizes, of a 4 mm thickness, linked by means of special connectors IP67.

Customized system is manufactured in accordance to the area to be covered plan and do not require special connection as is connected to a single electrical power outlet. Installed power depends on the heat requirement of the building where the system will be installed



Installation of modular elements and their linkage by means of special connector.

The installation of the customized panels is even easier, it requires only be lying down and connecting to the electrical system in the preset point.

Fast installation and absence of thermal inertia

Compared to a hydraulic system, the carbon fiber system produce the heat locally, it has the highest efficiency and reaction. During the heat production and distribution phases no dispersion occurs.

The position of the heating element depends on your choice and needs: more or less close to the surface, providing different thermal inertia. For example, by installing the panels under a cement screed, the inertia increases, which can also be an advantage in case of continuous use of a room. From time to time, the installation stratigraphy type must be decided depending of the various needs.

This power of the heating system is lower in comparison to the conventional systems, due to the fact that the thermal energy is produced directly under the used area and not in a farthest corner of the building where the thermal power plant can be located, the heat dispersion through the transport pipes may be considerable.

Reduced Dimensions

Carbon fiber panels electrical heating system occupies less space in comparison to traditional heating systems:

- reduced thickness of heating panel – 4 mm;

- requires no chimney, because the system produces no flue gas;
- does not require distribution boxes, housings for pumps and valves, but only electrical cable.

No maintenance cost

This type of system requires no maintenance, occasional or periodic replacement of its components, since there are no moving parts, subject to wear. There are no components requiring periodic review.

Temperature control

Electrical heating systems, unlike the hydraulic systems, can be easily controlled, since the devices must control electrical power passage and not the liquid's (there are no pumps, valves, pipes and fittings that often cause heavy maintenance operations).
Proper temperature control allows maintaining low thermal gradients between floor, wall and air. An increased temperature difference between areas diminishes the comfort.
Wall low temperature requires a high temperature of the floor.
If the system is built according to the thermo technical calculations, with a control as described earlier, makes the ambient temperature to always be close to the set point values, without ever reaching 0.1 / 0.2°C.In this way the temperature of the floor surface remains at a stable temperature compared to the set point in the air.

Heating systems is controlled by an electronic unit at which are connected the temperature probes and heating elements supplies.

For the modulation work mode it is necessary to install an outdoor probe or an ambient probe for each room (or both).
In this mode, to each output is assigned an operating value from 0 to 100, this value is calculated according to both outside and inside temperature.

For a building the maximal dispersion value is calculated, in conditions of minimal outside temperature of the project. Based on the maximal dispersion the system is projected with an electrical power calculated from the thermal engineering project, and increased with a small percentage.

For outdoor temperatures above the minimum temperature of project, the dispersion is reduced, you can heat the room with a power lower as the one installed.
The unit is equipped with relay output, so you can not reduce the power by cutting the half-wave, but the output can only be turned on or off.
To reduce the power of the system - for example 70%, is used a method whereby an output stays on for 7 minutes from 10 minutes. In this way the amount of heat and power consumption is lower.

Operation percentage calculation:

If the outside temperature is equal with the project temperature (i.e. -5°C) operation percentage must be 100%. If the outside temperature is 7.5°C, the operation percentage may be even 50% (as the thermal losses are diminished).
Two factors must be calculated (or percentage of operation that the system must have), which are:

- Percentage based on outside temperature
- Percentage based on the inside temperature

The percentage of outside temperature (result PERC_TE 0-100%) is calculated as follows:

perc equal with 0 when outside temperature is higher than 20°C.
perc equal with 100 when outside temperature is -5°C.

The percentage of ambient temperature (result PERC_TA 0-100%) is calculated as following:

perc equal 0 with a temperature higher than set point temperature
perc equal with 100 when the temperature is lower or equal with the set point temperature of -5°C.

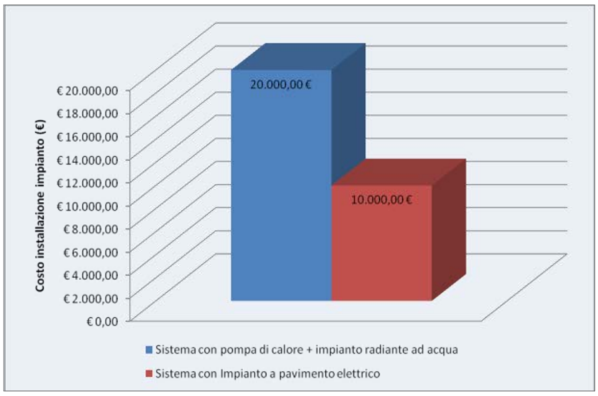
Example for set temperature (set point) of 20°C, set percentage of 100% with temperatures lower or equal 15°C.

The percentages interact according to the following formulas:
percentage output = PERC_TA * 0,6 + PERC_TE *0,4

There may be an installed temperature sensor integrated into the heating surface (typically the floor), which is limiting the surface temperature to a preset value (i.e. 24°C at the floor level).

Comparison between another electric system

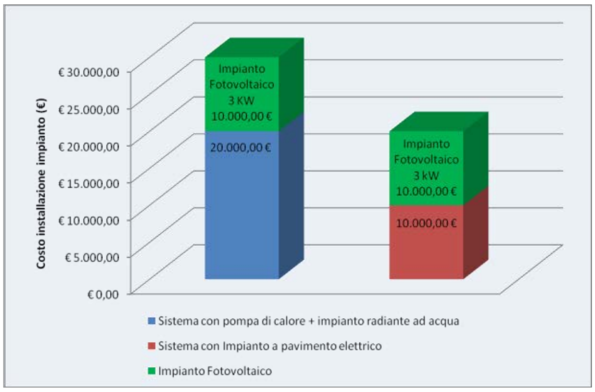
Bringing a concrete example, we can compare two heating systems using two new technologies. The first system consists in an air heat pump; room heating with water tube radiant floor, system's operating adjustment for each environment. The second system consists of an electric radiant floor heating system made of carbon fiber, with management for every single environment.
Taking as a reference single-family dwelling with an area of about 150 m2, the cost of installation can be estimated as follows:



Heating system: heating pump + water radiant floor

Electric floor heating system

The comparison of the initial expense between the twosystems shows that the choice of a geothermal heat pump system, as energy-efficient as it is, may be too economically burdensome for the user. The electric floor heating, although slightly more expensive with respect to the operating costs, is characterized by a significantly lower installation costs. With the addition of a 3 kW power photovoltaic system, the estimated cost for the systems turns as:

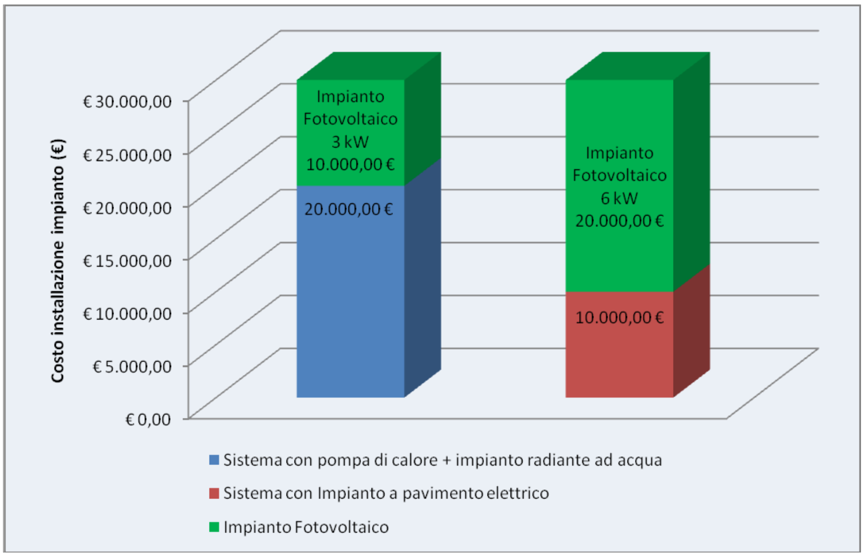


Heating system: heating pump + water radiant floor

Electric floor heating system

Photovoltaic system

The reduced installation costs for an electrical floor heating systems allows the customer to use the eventual remaining economic resources to install an increased power photovoltaic system. For example, the savings made installing an electrical floor heating system instead a system with heating pump and radiant water floor can be used to install a 6kW power photovoltaic system instead a 3 kW one.



Heating system: heating pump + water radiant floor

Electric floor heating system

Photovoltaic system

Assuming a primary energy needs for heating the building equal to 4500 kWh per year, with the heat pump (COP = 2.5) the electricity to be consumed (taking into account the operation of the circulating pumps for water in the system) is equal to 2500 kWh / year.

For an electric radiant floor system (with an estimated yield of 125%) the annual energy supply is about 3600 kWh / year.

For the same cost (i.e. 30 000, 00 €) the customer benefits a photovoltaic system with double power: the electricity produced "in excess" can be sold to the electricity operator, becoming a source of income for the user.

The comparison shows therefore a net benefit of the system electric radiant floor heating.

This type of heating system fulfills the requirements of the regulations in force on both energy efficiency and use of renewable resources and, last but not least, there is no source of income and not expenditure for the end user.

Ecodesign of decentralised and air-based centralised heating products

Shailendra Mudgal, Adrian Tan, Sandeep Pahal and Alvaro de Prado Trigo

BIO Intelligence Service

Abstract

Over 60% of the energy consumption of households in the EU is used for heating. Space heating has therefore been identified as one of the greatest sources for energy savings. To date boilers, heat pumps and solid fuel heaters have already been analysed to identify possible ecodesign requirements under the Ecodesign Directive [1].This paper reports on the preparatory studies (currently in progress) of the remaining space heating products for residential purposes that exist on the market, but have not yet been investigated. These are local room heaters (ENER[1] Lot 20) and central heating products that use hot air to distribute heat (ENER Lot 21) [2].

In a similar manner as with the other space heating appliances already examined, the ENER Lot 20 and 21 preparatory studies use a common ecodesign methodology [3] for analysing products and investigating possible measures to improve their energy and environmental performance. The studies take into account the life cycle perspective of products and follow a logical series of steps: scope definition, market analysis, user behaviour aspects, systems analysis, environmental assessment of the current products, and improvement potential achievable through product design. The improvement options consider life-cycle costs (LCC) and the point of lowest life-cycle costs for the consumer is identified as a short-term target for ecodesign requirements, whereas the "best available technology" option might serve as a future target. This paper summarises the initial findings of the first three tasks from the ENER Lot 20 and 21 preparatory studies.

Background

The Ecodesign Directive (2009/125/EC) [1] is an integral part of the European Union's policies addressing sustainable consumption and production (SCP). Inspired by the Integrated Product Policy (IPP), this Directive adopts a life cycle oriented approach to product design in order to reduce the overall environmental impacts of products. The Ecodesign Directive establishes a framework for setting ecodesign requirements for products that cause significant environmental impacts and have significant improvement potential. Taking into consideration the existing voluntary and mandatory measures, the Ecodesign Directive may put forward generic or specific ecodesign requirements through so-called 'Implementing Measures'. Such requirements may include power consumption thresholds, efficiency levels, mechanical design and material use restrictions, requirements on labelling and consumer information, etc. The Ecodesign Directive is a rather unique initiative which attempts to improve the energy and environmental performance of products during the design phase itself, while taking into account industry, consumer, and other stakeholders' concerns in order to effectively move the market to sustainable development.

The Ecodesign Directive by itself does not provide binding requirements for specific products, but provides the framework, and defines the conditions and criteria for introducing directly binding requirements (Implementing Measures). A product category shall be covered by an Implementing Measure when it:

1. represents a significant volume of sales in the EU market (indicatively > 200,000 units a year)[2];
2. involves a significant environmental impact; and,
3. represents a significant potential for improvement.

[1] ENER refers to Directorate General for Energy

[2] Please note that the indicative threshold relates to annual product sales of all product types within a lot. Even though for certain product types (especially for those covered in the ENER Lot 21 study) the annual product sales might not reach the indicative threshold of 200,000 units, the Commission may very well choose to proceed the investigation of setting ecodesign requirements for the products in the study.

In accordance with Article 15 of the Directive, the Implementing Measures have to be based on:

1. an analysis of the whole life cycle of the product and all significant environmental aspects
2. an assessment of impact on the consumers and manufacturers

These aspects are investigated in a preparatory study, which is the first step in identifying and recommending ways to improve the environmental performance of products within the relevant provisions of the Ecodesign Directive. All preparatory studies follow a common approach: the Methodology for Ecodesign of Energy-using-Products (MEEuP) [3], which is based on a comprehensive set of data on key issues such as market information, best available technology, improvement potential and options. In brief, this methodology includes a definition of the product categories (task 1), market analysis (task 2), aspects of user behaviour and related barriers for ecodesign (task 3), analysis of real products being identified as representative of the European situation (task 4), environmental assessment of average products defined as Base Cases, system analysis (task 5), in depth technical analysis of best available (and not yet available) technologies and possible improvement potential of different design options (tasks 6 and 7), and policy and scenario analysis (task 8). The MEEuP also includes a simplified LCA tool (EuP EcoReport) using an internal database that converts material quantities from the Bill of Material (BOM) of products, energy consumption data and economic data into standard environmental indicators and Life Cycle Cost (LCC) data.

It is common to observe that the market for any type of product, including the heating appliances covered in ENER Lots 20 and 21, exhibits a wide range of varying degrees of sustainability (Figure 1). The Implementing Measures proposed under Ecodesign include options targeting the entire range of products, e.g. limiting the least sustainable products and promoting the best environmentally performing products.

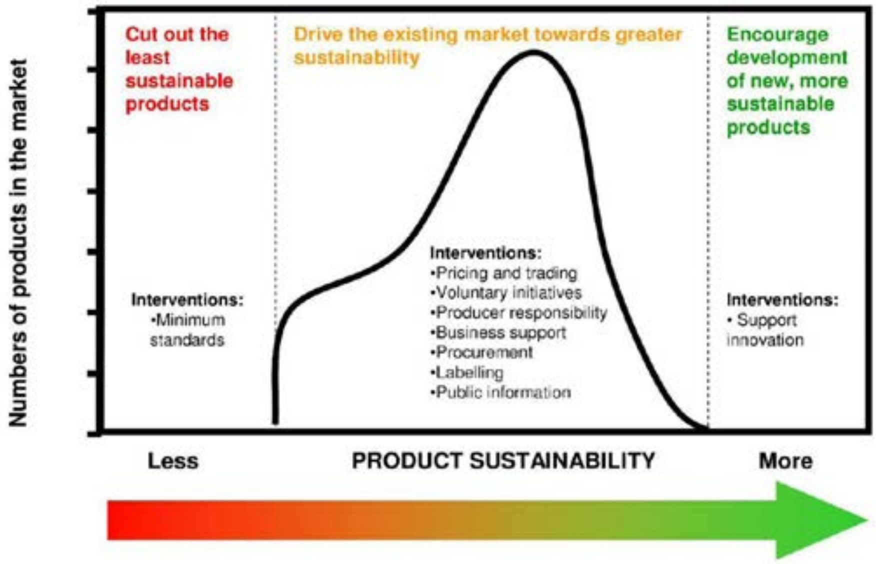


Figure 1. Product policies aim to eliminate the least energy efficient products from the market and drive the entire market to more sustainable products.

Source: Defra, UK (2009) *Saving Energy Through Better Products and Appliances. A consultation on analysis, aims and indicative standards for energy efficient products 2009 – 2030*, December 2009.

Since 2005, analyses of different product groups have been performed and resulted in detailed ecodesign requirements for specific products. These requirements are developed in a multi-step process (see Figure 2):

1. **Working Plan**, based on a study [4] a first working plan for the Ecodesign Directive was drafted by the Commission. The working plan established a list of product groups that would be considered in priority for the adoption of Implementing Measures in the period 2009 - 2011.

2. **Preparatory Studies,** conducted by independent consultants, analyse a specific product category regarding environmental performance throughout the full product life cycle and regarding improvement potentials, i.e. technology options with significantly lower environmental impact at any life cycle step. A wide range of stakeholders are consulted during these studies.

3. On the basis of the preparatory study, the European Commission outlines possible product requirements in a **Working Document**, which are presented and discussed at a **Consultation Forum** meeting with a broad representation of stakeholders.

4. Based on these discussions and further evidence, the European Commission drafts an **Implementing Measure** for vote by the **Regulatory Committee**.

5. After an inter-service consultation at the Commission, a scrutiny by the European Parliament, and a **notification to the WTO**, the adapted **Implementing Measure / Commission Regulation** is adopted and published in the **Official Journal of the European Union**. The requirements laid down in the Implementing Measure are **directly effective** in all the Member States from the date of its publication itself.

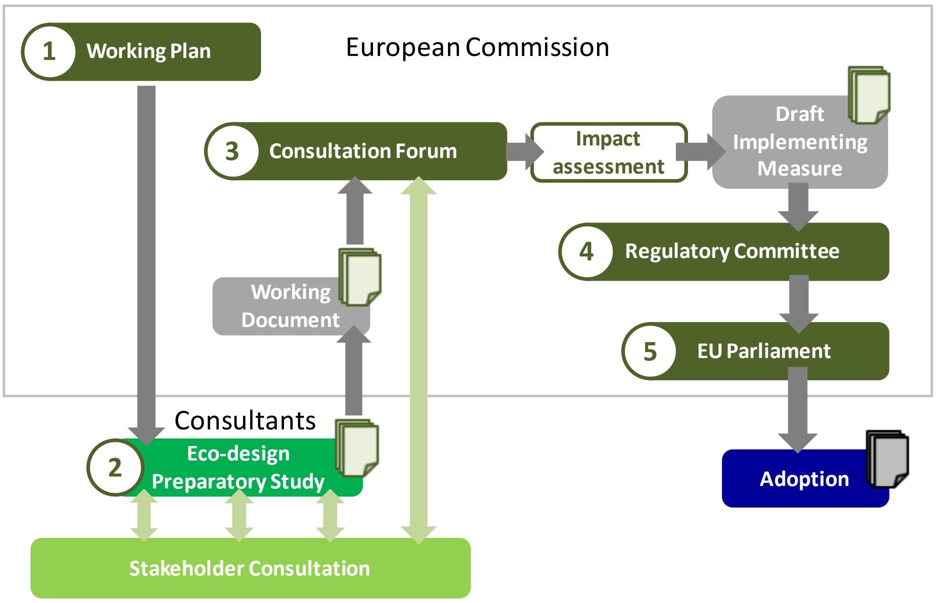


Figure 2. The process from preparatory study to implementing measures.

To date preparatory studies for 33 lots or product groups have been launched. This has so far resulted in 11 Implementing Measures, which is estimated to result in about 222 TWh of annual energy savings by 2020 (this is almost 8% of the 2007 electricity consumption in the EU) [5].

Definition of local and central heating appliances

Space heating is the largest component of household energy use (over 60%) in the European Union (EU) and is already identified as a priority by the European Commission as it also represents significant energy efficiency potential [6].

Local room heating products can be defined as appliances that provide heat to indoor spaces by generating heat at the same location as it is emitted. They are self-contained heating units that can be either portable or installed. Installed heaters are typically used as the primary heating system in buildings, whilst portable heaters are often used as secondary heating (to supplement or substitute the primary heating) or for spaces where no heating system is installed. The most common types of local room heating products (excluding solid fuel appliances) are electric heaters, but liquid and gaseous fuel heaters are also popular.

In contrast air-based central heating systems generate heat at one central place, such as a furnace room in a house or a mechanical room in a large building, which then gets distributed, typically by forced-air through ductwork. Boilers use water to distribute heat in so-called hydronic systems, whilst furnaces use air to distribute heat.

Interaction with other space heating products already covered by Ecodesign

Under the Ecodesign Directive, several preparatory studies have already investigated heating products, such as TREN[3] Lot 1 (central heating boilers, www.ecoboiler.org), TREN Lot 2 (water heaters, www.ecohotwater.org), TREN Lot 10 (room conditioning appliances, www.ecoaircon.eu), TREN Lot 15 (solid fuel small combustion installations, www.ecosolidfuel.org), DG ENTR Lot 6 (air-conditioning and ventilation systems, www.ecohvac.eu), ENER Lot 22 (domestic and commercial ovens, www.ecocooking.org), ENER Lot 23 (domestic and commercial hobs and grills, www.ecocooking.org).

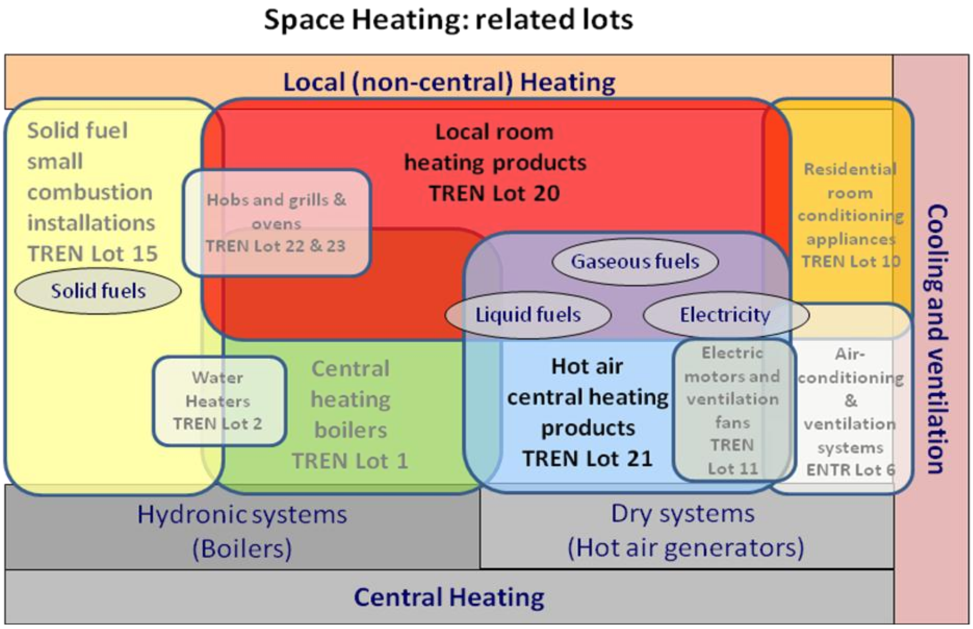


Figure 3. The interfaces and differences in scope of the Ecodesign preparatory studies compared to local room heating products

Some local room heating products already fall into the scope of TREN Lot 15 (small combustion installations, e.g. wood fireplaces, coal stoves, etc.) which explicitly includes direct heating products whose energy source derive from solid fuels (coal, biomass, pellets, etc.). The ENER Lot 20 study focuses on the other fuel types, such as electricity, gas, and liquid fuel.

Central heating products are covered in TREN Lot 1 and ENER Lot 21: hydronic (using water to distribute heat) and dry (using air to distribute heat) systems, respectively. Both these product groups rely on the same heating principles (i.e. heat generation, distribution and emission are separated) and are alternative solutions to meet the same functional needs, i.e. indoor space heating.

TREN Lot 10 includes residential air-conditioning appliances that besides cooling are also capable of providing heat (reversible air-conditioners or heat pumps)[4], but do not consider appliances that solely provide heat for indoor spaces. Likewise some cooking appliances have a dual functionality of space heating, but these are expected to be covered in ENER Lot 22 as their primary function is cooking.

Analysis of decentralised and air-based centralised heating products for

[3] TREN refers to Directorate General for Transport and Energy

[4] Residential air conditioners are defined as heat pumps below 12 kW power capacity.

residential use

Although the preparatory studies for ENER Lot 20 and 21 also encompass heating products used in commercial and industrial buildings, this paper focuses on the products used in residential buildings to provide comfortable heating for living spaces.

Types of heating products

The scope of residential appliances in ENER Lot 20 can be broadly characterised as follows:

1. **Electric heaters**:

   a. *Installed heaters*: convector panel heaters, radiant panel heaters, radiators (including towel heaters), fan heaters (including electric fireplaces), ceramic heaters, glowing radiant (infrared) heaters, storage heaters and underfloor (thin film and cable) heating systems, etc.

   b. *Portable heaters*: convector panel heaters, radiant panel heaters, radiators (including oil or fluid filled heaters), fan heaters (including electric fireplaces), ceramic heaters, glowing radiant (infrared) heaters, etc.

2. **Gas heaters**: flued gas heaters, flued gas fires, flueless systems (installed and portable gas fires and gas heaters), etc.

3. **Liquid fuel heaters**: paraffin/kerosene heaters and liquid fuel fire (ethanol-gel fires)

As mentioned there is a difference in use for installed and portable heating appliances. Installed space heaters (built-in or fixed to the building shell) are typically used as the primary heating system for an indoor space (i.e. provides heat for most of the heating season). Portable (or freestanding) heaters tend to be more used as secondary heating systems to supplement or substitute the installed primary heating system (i.e. only used for a few hours on cold days). Portable heaters are also used when no heating system is installed at all. The two types of heaters also differentiate in purchase price, average power capacity and distribution. Installed heaters are typically installed by professionals and therefore dimensioned correctly for the space and use. The average power capacity per unit of installed heaters (~1.0 – 2.0 kW) therefore tends to be lower than the average portable heater (~2.0 kW). Portable heaters are often bought ‘off the shelf’ at DIY stores and can be much cheaper than installed heaters – sometimes as low as €10-30. On average installed heaters are two to three times more expensive to purchase than portable heaters.

Within the scope of ENER Lot 20 is also industrial (warm air) unit heaters (electric, gas and oil), electric radiant cassette, radiant gas-fired heaters (luminous and tube) and air curtains, but these are not used for residential purposes. Sauna heaters and outdoor heaters (e.g. patio/terrace heaters) were considered in the study, but will probably be dealt with separately by the Commission as their functionality is different.

Although common in North America, air-based central heating is not often used in residential homes in Europe. The only relevant residential appliances considered to be within the scope of the ENER lot 21 study are indirect fired furnaces below 19 kW (≈ 65,000 BTU per hour). The ENER Lot 21 study will also deal with direct gas-fired furnaces, air handling units and heat pumps (over 12 kW power capacity), but again these products are mainly used in the non-residential sector, and therefore not described any further in this paper.

Existing legislation and standards

Test standards are a prerequisite for introducing minimum energy performance standards (MEPS) as implementing measures. In order to implement a specific performance requirement there must be a well-defined method for testing product compliance. Many test standards on safety and energy performance exist for ENER Lot 20 and ENER Lot 21 products. These standards are not presented here but are detailed in the ENER Lot 20 & 21 Task 1 reports [2]. Besides ensuring safe operation, end-of-life disposal and the restriction of use of certain hazardous substances, existing legislation in the EU does not specify any specific energy performance requirements for space heaters covered in ENER Lot 20 and 21. As Australia, Canada, Russia, Japan and the USA have already both mandatory and voluntary programmes for MEPS of space heating appliances in place, it would seem pertinent to introduce similar measures in the EU.

Several different types of energy efficiency performance metrics are used in standards. The energy conversion efficiency of appliances that generate heat from combustion is determined by the ratio of the useful output heat and the energy (electricity and fuel) used. This can be measured in several different ways:

- *Efficiency of electric heaters* is determined by the *Joule effect* where all electricity is converted into heat. In practical terms, the product efficiency in electric heaters is nearly 100%.

- *Combustion Efficiency* is a measure of the gas and oil burner's ability to burn fuel. It is determined by measuring the amount of unburned fuel and excess air in the exhaust. Well designed burners firing gaseous and liquid fuels operate at excess air levels of 15% and result in negligible unburned fuel. By operating at only 15% excess air, less heat from the combustion process is being used to heat excess air, which increases the available heat for the load. Combustion efficiency is also dependent on the type of fuel.

- *Thermal Efficiency* (TE) is the energy conversion efficiency of heaters under steady-state peak conditions. It is determined by the ability of the heat exchanger in indirect-fired systems to transfer heat from the combustion process to the warm air used for space heating. TE is often specified as net or gross depending on whether the net or gross calorific value of fuel is used. The net calorific value of a fuel excludes the latent heat of water vapour in the exhaust, and so is lower than the gross calorific value. Efficiency test results and European standards normally use net calorific values. As warm air heaters are not always used at full heat loads, it is not a good indication of actual efficiency.

- *Annual Fuel Utilization Efficiency* (AFUE) is more commonly used as an indicator for actual energy efficiency in North America. AFUE takes into account the cyclic on/off operation and associated energy losses due to changes in loads during the heating season.

- Radiant heaters' efficiency is given by the *radiation factor* (in %), which measures the share of the energy converted into radiant heat.

- The efficiency of local room heaters at *system level* should include insulation factors, energy losses, and interaction of the product, the heating demand and the user. Standards such as EN 15316-2-1: "Heating systems in buildings – Method of calculation of system energy requirements and system efficiencies" already include energy efficiency from a system perspective.

The Energy Performance of Buildings Directive (EPBD) does also impose requirements for the energy consumption in buildings which includes heating systems. It is up to each Member State to apply a calculation methodology and set requirements concerning the energy performance of new and existing buildings, but this does not directly specify requirements to individual heating products. The best choice of heating system for a building depends on its application and the specific context. It is not the intent of the Ecodesign Directive to specify what heating system should be installed in buildings, but rather to ensure that only efficient heating products are installed in buildings whatever the type and application.

Market stock and sales data

The market information for the ENER Lot 20 and 21 studies is currently being collected and has not yet been verified. However, it has been thought-provoking that although heating constitutes a large share of the total EU energy consumption and represents considerable saving potential, very little sales and stock data exist for the EU's heating systems. In order to gather this information, data had to be pieced from stakeholders and older studies.

BRG Consult attempted in 2006 [7] to characterise the heating market in EU-25 by taking into consideration regional, national and EU level patterns. According to the study, of all the 208 million dwellings in EU-25, about 17.5 million to 21 million dwellings use local room heating products (~ 10%). It further estimates that around 25% of these dwellings are located in Spain; 15% in Italy;

around 10% each in Portugal, France, Germany and Poland; around 5% each in Greece and Hungary; and, the smaller shares in the remaining EU countries. As the focus in the BRG study was on boilers (hydronic central heating), not much detailed information was provided on the products covered in ENER Lot 20 and 21. To gather more detailed and updated market data, questionnaires were sent to all registered stakeholders of the ENER Lot 20 and 21 studies. The results of the responses are shown in Table 1.

Table 1. Sales and stock in EU-27 of residential heating products covered in ENER Lot 20 & 21 (average of 2007 - 2009).

Space heater	Estimated sales (in 1000 units)	Estimated stock (in 1000 units)
Electric installed heaters	13,000	127,000
Electric portable heaters	8,000	61,400
Local room gas heaters and fires	4,250 – 4,750	12,850 – 16,070
Local room liquid fuel heaters and fires	500	?
Central heating gas furnaces (for residential use)	?	670
Total	*~ 26,000*	*~ 200,000*

Source: Stakeholder input, various studies and own estimates

Electric heating is common in France as most of the electricity is produced by nuclear power. Just under 4 million electric panel heaters were installed in 2009. Besides France, the Nordic countries are also major markets for electric heating, particularly with underfloor systems. Gas (direct) heating is traditionally popular for residential heating in Ireland and the UK, but also Germany and the Netherlands seem to comprise significant markets. Very little market data is available for liquid fuel space heaters for residential use, but several stakeholders have observed an increase of popularity of ethanol fires (appreciated as much for their decorative live flame as for providing heat).

During the 1970s central heating gas furnaces were popular with new residential house builds in the UK. Now it is estimated that only around 400 000 residential dwellings in the UK use indirect gas-fired furnaces as central heating. The UK represents almost 60% percent of the overall market share of the current stock of these furnaces in the EU.

It is estimated that the average product prices[5] for the ranges of capacity concerned in ENER Lot 20 study are between 20-1000 €/kW for electric heaters (portable heaters are much cheaper to buy than installed heaters), 10-312 €/kW for gas heaters and 13-295 €/kW for liquid fuel heaters.

Market and technology trends and outlook

The key factors influencing the future market of local room heating appliances are:

- Building regulations (e.g. building codes, Energy Performance of Buildings Directive (EPBD))
- Energy and environmental legislation (e.g. taxes and subsidies)
- Energy prices
- General economic situation
- New construction
- Replacement of old heating systems

[5] 'Average' product price in this context is not understood as an arithmetic mean, but more as a representative price for a typical average product in each category.

Some of the mega trends which will influence the market of local room heating products are macroeconomic conditions and demographic trends. For example, consumers may postpone installing central heating systems in an economic recession and opt for more affordable portable heaters. Or, more people will choose to live alone or in bigger houses.

Energy and environmental legislation related to construction and energy consumption will certainly be key drivers for the residential market and will influence the size and power capacity of products. Better insulated buildings have smaller heating demands and will therefore require smaller power capacities. Some manufacturers expect the market for local room heaters to slowly decline as better insulated houses and central heating systems (condensing boilers and heat pumps) become more common. Regarding portable heating devices, these are not covered by building regulations. As they are relatively inexpensive to buy, consumers may choose them to boost heating in some specific areas of their house, instead of turning on (or increasing the temperature) of the primary heating system.

Energy policy will directly influence the growth or decline of certain products. The security of gas supply might discourage the demand for gas appliances in some Member States, or alternatively be considered a better environmental choice compared to electric systems, if the production of electricity is mostly based on fossil fuels. Specifically for installed electric heating systems, e.g. storage heaters and underfloor heating, these types of products could play an important role for load shifting and Smart Grids, as they can be demand controlled.

Consumers will also demand products and systems that are well-integrated designs which can provide the right temperature and thermal comfort in their living spaces. Here new heating and control technologies will influence the market, e.g. presence detectors, open window sensors, etc. The demand for decorative heating appliances could also drive the demand for many local room heating products. In many Member States the existing stock of heating systems are relatively old (more than 20 years). When the financial situation improves, consumers may want to change their heating system to have more comfortable and efficient heating.

With electric heating products, there is a general trend that radiant panels and electric radiators are slowly replacing convectors (particularly those with mechanical controls). This is driven by the perception of the heat comfort that the different technologies provide. End-users perceive the heat from radiators to be more comfortable as the appliances are always warm and deliver heat at a lower temperature, which is more evenly distributed. Besides heaters used in bathrooms, e.g. towel heaters, fixed fan heaters are a marginal market. In well-insulated houses, where the heating demand is reduced, electric heating can be an energy efficient choice. Electric underfloor heating systems are believed to be a growing market.

For gas heaters, the sales of radiant convectors and wall heaters are expected to decline due to losing market share to electric heaters. The sales of live fuel effect gas fires faces competition from solid fuel fires. Sales are thought to remain stable or maybe even increase slightly. Decorative gas fires (mainly a UK product) are in decline, losing market shares to electric, solid fuel and more efficient live fuel effect fires. The market for flueless gas space heaters is thought to be growing as many new properties do not have chimneys installed in them. Many of the residential local room heaters are chosen more for their decorative features rather than their ability to provide heat. It is therefore often perceived as a ‘luxury product’ to create a certain ambience in a room.

Besides the growing demand for air conditioners (or heat pumps which can also provide heating), the sales of air-based central heating products are expected to diminish in the residential sector. A major limitation of air-circulating systems in homes compared to hydronic (water-based) systems, is the space taken up by air ducts compared to hot water pipes.

Product life

Purchase and installation

The choice of a space heating appliance is influenced by many factors. The building type, size of area to be heated and its uses are typically considered together with purchase price and operation costs. The choice of heating system is often limited by the availability of a public supply of gas or electricity. For buildings not connected to gas mains, it is possible to have a LPG storage tank installed or use cylinder gas. This however represents an additional investment. Customers tend to choose the energy sources that are already readily available to them.

For customers in the residential market who also use the appliances they buy themselves (such as homeowners), thermal comfort is the main criteria driving the market for installed direct heating in homes. Thermal comfort from residential end-user's point of view includes aspects such as:

- Heat quality: comfort is related to heat quality, or 'soft heat' (not only provided through convection heating but also a large, soft and stable part of radiation base heating technologies)
- Heat inertia of the heating appliance especially for poorly insulated houses
- Air quality (air between 40% to 60% of local humidity grade and no air movement superior to 0.2 m/s)
- Level of temperature homogeneity in the room
- Quick heat ramp up (usually less than 2 hours to go from 15.5°C to 19°C)

In many cases, consumers purchase portable local room heating products to compensate for issues related to wastage of energy in their homes, such as a poorly maintained furnace, inadequate insulation, and missing caulk around windows or damaged weather stripping around doors.

Although residential end-users might be concerned with their energy consumption, they are often not aware of the difference in energy efficiency among competing products and fuel types due to the absence of energy efficiency labels for these products.

As mentioned local room heating products are not only purchased to heat up a room but are also often seen as a decorative piece in homes by consumers. In particular for direct heating appliances used in residential buildings, besides the principal heating function of the appliance, other factors like aesthetic pleasure and design are also important criteria. For example, fireplaces may sometimes be chosen because of their decorative appearance and ambiance rather than for the heat they generate.

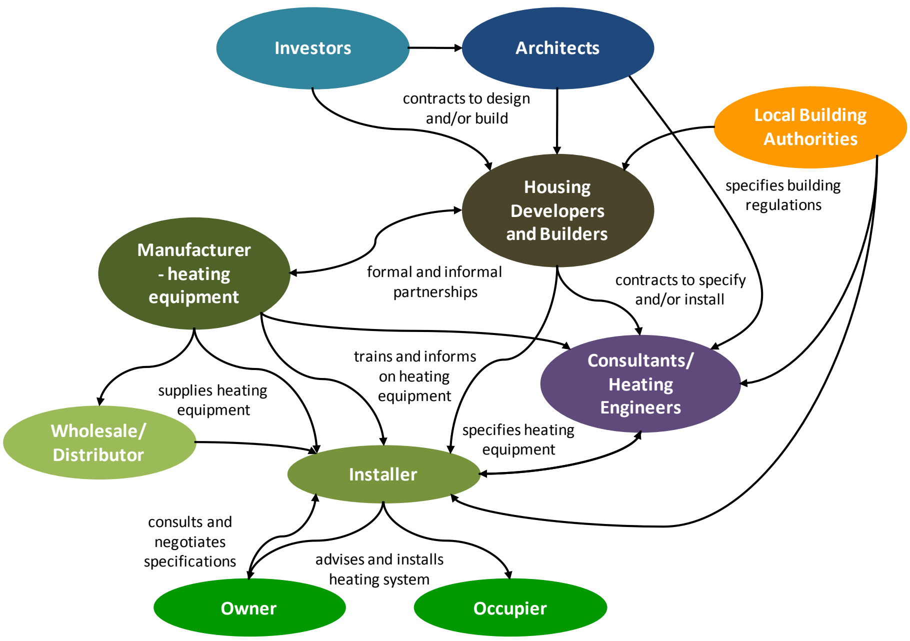


Figure 4. An example (not generic) of what actors are involved in the specification of installed heating equipment

There is no evidence that local room heating products in Europe have caused any health or safety incidents. There are however cases of electric portable (mostly imported) heaters that are called back each year by distributors due to product defaults and non-compliance. Therefore, safety and its perception among end-users also plays a role during customers' (particularly those with children in residential applications) buying decision of these heating products.

Depending on the sales channel of local room heating products, different heating professionals influence consumers on their choice of heating system. See Figure 4 for an example of actors that are implicated in the process of choosing a heating system.

Use and maintenance

Climatic conditions and user preferences for indoor air temperature are the main factors in determining the frequency and the characteristics of use (temperature and timer settings) of heating appliances. In the EU, available long-term measurements of indoor preferred residential temperatures give the level of 18°C in United Kingdom, 20°C in Ireland, and 21-22°C in Sweden. In South-East Europe, substantially reduced indoor temperatures have been a reality during the recent years for the poorest part of the population with respect to affordability. Energy consumption and end-user patterns of heating products also depend on the nature of the building envelope (e.g. materials used for construction, air-tightness, etc.). In addition, heat will be lost and gained depending on levels of insulation and ventilation.

As mentioned, the type of heating product in question may also be important in terms of frequency and characteristics of its use. Heaters which serve as primary heating are used for several hours a day during the heating season. Heaters used for secondary heating may only be used irregularly and only for a few hours at a time. Heaters used as primary heating may benefit from automatic controls, while heaters used as booster heat are typically manually controlled. Manually controlled appliances may require more frequent operator intervention, whereas in the case of automatic appliances, more dynamic temperature controls are often adjusted automatically according to the outside temperature.

To some extent housing family size and age of occupants also affect the use pattern of residential heating products. Occupant behaviour, such as individual levels of thermal comfort and hours of occupancy will affect the energy consumption of residential heaters. The role of age of end-users has been the focus of several studies that estimate space heating consumption. Empirical studies have been carried out in Japan, Norway and USA confirms the positive correlation between residential consumption for space heating and the age of the household's members [8]. Elderly persons prefer higher room temperatures and in general tend to stay at home more than younger persons. Some studies have also looked into household size as a variable for energy consumption for home heating. It is estimated that household family size is a positive and significant parameter of the choice of dwelling size, which in turn affects households' demand for space heating [8]. The study findings show that particular household composition, such as the existence of a baby as a family member significantly and positively affects the amount of energy consumed for space heating.

For electric space heaters, there is no need for other maintenance than removing dust with a damp cloth, broom and/or vacuum cleaner. Installed gas and oil heaters are subject to annual service checks, but most portable heaters are not.

End-of-life

Most local room heating appliances have few moving parts (typically only those with fans) and they are made of durable materials due to safety reasons. Hence, their wear is generally low and their lifetimes are long. The typical technical lifetime of these appliances is in the range of 10-30 years. Replacement of direct heating appliances is rarely due to technical failure of the appliance, but rather to the wish of the user to install a better performing appliance or change the interior design of the indoor space, for example at the occasion of a house renovation. The economic lifetime of these appliances is estimated to be in the range of 5-20 years.

Electric room heaters fall under the scope of the WEEE (Waste from Electrical and Electronic Equipment) Directive (category 1) under large household appliances (electric heating appliances, electric radiators, other large appliances for heating rooms). The Directive aims to improve the recycling and reuse of electrical and electronic equipment at the end of their life rather than sending them to landfill. Another aim of the legislation is to encourage better design of electrical and electronic products to ensure that they can be recycled easily and more efficiently. On average both the disposal costs and resale value (as scrap metal or second-hand product) for ENER Lot 20 appliances are considered negligible.

Estimation of total energy consumption in the EU

Based on the market and user data received to date, it is possible to give a first estimate of the total annual energy consumption of the residential heating products included in the scope of the ENER Lot 20 study. The annual energy consumption of each product type was calculated by multiplying the EU-27 average number of heating days in the year (based on the heating degree days) by the daily average heating duration (depending on primary or secondary heating), the estimated operating rate (it was estimated that the heater operates at 20-25% of its maximum power capacity during the heating period) and the average unit capacity for each heater. These values were then multiplied by the stock estimate and summed in order to get the overall EU-27 energy consumption of each type of heater. Given these assumptions and the available data, it is estimated that the local room direct heating residential appliances considered in ENER Lot 20 consume between 54 to 66 TWh of electricity, and between 14 and 17 TWh of gaseous and liquid fuel every year in EU-27. As more primary energy is needed to produce electricity, the amount in primary energy is higher depending on how the electricity is produced. Given the lack of market data concerning the ENER Lot 21 products, the same evaluation could not be carried out.

Design options and efficiency improvements

In relation to the energy efficiency of heating products, it is worthwhile noting that it is just as much the efficiency of distributing heat where it is needed, than the actual generation of heat, which will be essential in achieving significant energy savings. For both kinds of heating appliances, system perspectives come in to play such as room temperature, room insulation, ventilation and the installation/placement of heater.

As local room heaters provide heat directly (many appliances are close to 100% efficient measured as the ratio between energy consumed and heat delivered), the greatest improvements in (system) efficiency come from better control and regulation. In the residential sector more user-friendly controls, and even controls that urge users to use less energy, will become important. Presence and 'open window' detectors exist on some heating devices, but are not yet common. Heating controls are slowly evolving to become more intelligent in the way that they can anticipate user patterns, and adjust themselves automatically without having to have the user interfere. Anti-dust and other self-cleaning features will also play a role is some direct heating products.

For air-based central heating systems, so-called high velocity mini-ducts could be seen as improvement options to deliver both heating and ventilation in residential buildings. However, no matter what product specific improvement options can be proposed, the greatest source of energy savings, no matter which heating system is used to heat a space, comes from heating systems that are correctly dimensioned and used appropriately.

Further work

The next steps for the preparatory studies will be to model various scenarios (over a time horizon of 2012 -2030) to illustrate quantitatively the improvements that could be achieved through the increased market penetration of heating appliances with improved energy and environmental performance. First, a baseline scenario with a selection of existing products identified as representative of the European situation (base cases) will be defined to serve as a reference against which alternative scenarios can be evaluated. The environmental impacts and life cycle costs of these base cases will be assessed assuming that continuity is maintained considering the current market and technical trends. Based on an identification of best available technologies (BAT) and best not yet available technologies (BNAT), the environmental impacts and life cycle costs of these improvement options will be analysed. Finally, a policy assessment is made based on the scenarios analysed.

At the time of drafting this document, the preparatory studies for both local room heaters (ENER Lot 20) and air-based central heating products (ENER Lot 21) were still in progress. Stakeholders of the heating products described in this paper that are not yet involved, are invited to contribute and react to the results provided. This is best done by registering as stakeholders to the study on the project website: www.ecoheater.org

A reliable and coherent preparatory study is necessary to set ambitious, but feasible, ecodesign requirements. However, as much of the data and information that the technical, economical and environmental analysis is based on is not complete; the studies are very dependent on the active collaboration of all stakeholders for input and feedback. Only in this way can the studies ensure that the implementation of regulation will be successful and will ultimately achieve significant energy savings.

Acknowledgements

Besides all the registered stakeholders that have already provided input and guidance, we would like to thank Mr. Tobias Jakobs, Mr. Thomas Stueber and Mr. Jens Helpenstell from TÜV Rheinland (partners in this study) for the support provided on Member State legislation and standards at the EU level.

References

[1] Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products. 2009.

[2] BIO Intelligence Service. *Preparatory Studies for Ecodesign Requirements of Energy-using Products: ENER Lot 20 and ENER Lot 21*. Studies commission by the European Commission, DG Energy. (on-going). Project website: www.ecoheater.org

[3] VHK. *Methodology Study Eco-design of Energy-using Products Final Report.* Study commissioned by the European Commission, DG ENTR. 2005. See: http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm

[4] EPTA, PE International and NTUA. *Study for preparing the first Working Plan of the Ecodesign Directive*. Study commissioned by the European Commission. 2007. Can be downloaded: http://ec.europa.eu/enterprise/policies/sustainable-business/files/workingplan_finalreport_en.pdf

[5] European Commission, DG Enterprise and Industry. http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm

[6] European Commission. *Energy Efficiency Plan 2011*. COM(2011) 109 final. March 2011.

[7] BRG Consult. *The boiler and heating system markets in the European Union*. November 2006.

[8] Sardianou, E. *Estimating space heating determinants: An analysis of Greek households*. 2008.

Uninterrupted heating of an air-source heat pump during defrosting and improvement of energy efficiency

Ji Young JANG, Yong Cheol SA and Baik Young Chung*

Air Conditioning & Energy Solution Laboratory, LG Electronics, KOREA

Abstract

During winter operation, an air-source heat pump extracts heat from the cold air outside and releases the heat inside to the living space. Under certain outside air conditions, frost forms on the air cooled heat exchanger and decreases the heating capacity. Traditionally, reverse-cycle defrosting is a common method of frost removal. But it causes the interruption of heating during defrosting and also requires a period of time to reheat the cooled pipe of the indoor unit after defrosting. In this study, a new technology was developed called continuous heating, using only a hot gas bypass valve, can remove the frost from outdoor heat exchangers and supply the heating to the indoors. For this, a high temperature and low pressure gas bypass method was newly designed where low pressure is the main difference compared to common high pressure hot gas bypass methods. Various refrigerant mass flow distributions were examined and the most effective defrosting mass flow was 50% in this case. Heating capacity was increased by 17% because of continuous heating and the cumulated energy efficiency ($COP_{cu.}$) was increased by 8% compared to the traditional reverse cycle defrosting over 4 hours including two defrost operations. Also, cumulated energy efficiency was increased by 27% compared to electronic heaters that supply the same heating capacity during the defrost. It was shown that continuous heating and energy savings could be achieved without adopting expensive technologies.

1. Introduction

The variable refrigerant flow (VRF) systems are finding their way into residential and commercial buildings[1] , because these systems have precise capacity control and individualized thermal comfort capabilities with very high energy efficiency compared to any other air conditioning method.[2] A VRF system is a refrigerant system that varies the refrigerant flow rate with the help of the variable speed compressor and electronic valves to match the capacity of the system to the space cooling or heating loads in order to maintain the zone air temperature at the set temperature.

During winters, under certain outside weather conditions, the air-source VRF heat pump often operates with substantial frost formation on the Outdoor heat exchanger, and the frost layer has to be melted away periodically to keep a high heat Pump coefficient of performance (COP) and the heating capacity.

Defrosting can be carried out in a number of ways[3] : (1) Compressor shut down (2) Electric heating (3) Reverse-cycle (4) Hot-gas defrosting. From among these, the reverse-cycle defrosting (RCD) is the common method of frost removal and many papers studied the dynamic characteristics during the defrosting process on the air to air heat pump. Despite a large amount of studies on the performance of air source heat pump during defrosting operations[4][5][6], it necessarily causes the periodic interruption of indoor heating and the degradation of the winter seasonal efficiency. As a result, the heating ratio is usually 80~85% in real fields. Therefore, the objective of this study is how to improve the heating seasonal performance of an air source heat pump that required defrosting.

2. Non stop heating ideas with air-source heat pump

There are two general methods to provide uninterrupted heating or to increase the heating ratio of air source heat pumps. One method is using an electric heater and the other is the application of discharge hot gas bypass.

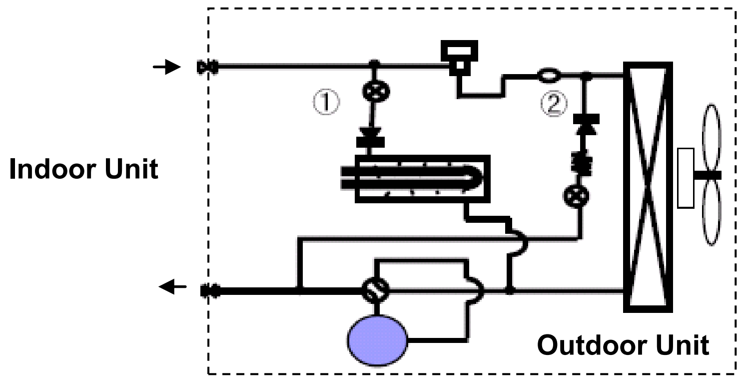


Figure 1. A general cycle of non stop heating model

Figure 1 shows a general model of non stop heating cycle. An electronic heater that is designed by considering evaporating capacity is generally installed in domain ① and supply deficient heat that is caused by frost. To remove frost from the heat exchanger, a hot gas bypass line that is extracted from the compressor discharge to heat exchanger is installed in domain ②. Both can be installed together or separately depending upon various situations with their own design purposes.

The application of an electronic heater is a very powerful, simple and direct method of non stop heating. It can supply heat without compromising a drop in indoor temperature during the defrost process and a heater situated outdoors performing the role of an evaporator can be more effective than direct location of the condenser indoors.. But it requires a relatively large size and additional expense if system capacity is increased. Also, there are some safety issues to consider such as the potential for short circuit, electric shock and fire. A hot gas bypass is simple and lower cost compared to the heater application but it reduces the indoor side heating capacity as well as the defrost refrigerant flux. Also, it requires more time to remove frost compared to the reverse cycle defrosting.

3. Applied hot gas defrost using dual spray

3.1 Schematics of dual hot gas spray defrosting

The most effective and low cost non stop heating cycle with dual hot gas spray method was designed as shown in figure 2. It was the same as the general hot gas bypass method that extracts hot gas from the compressor discharge but the heat exchanger was divided into two parts and each had its own extra valve.

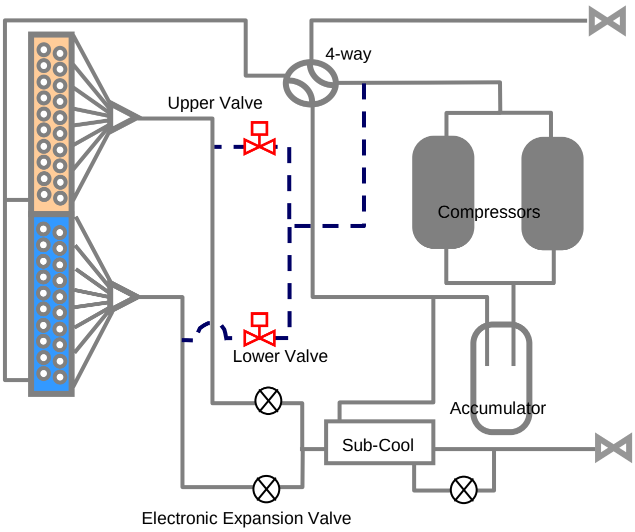


Figure 2. Dual hot gas spray cycle

Also, the existing single electronic expansion valve was increased to two. Under normal heating operation, two bypass valves are closed and two expansion valves are working equally. When defrosting started, the upper expansion valve closed and the upper hot gas valve opened to thaw the upper side frost and prevent the inflow of refrigerant which had to be evaporated. After the upper side defrosting finished, the lower side defrosting was performed with counter valve operations. When one side defrosting was going, the other side heat exchanger acted as a demagnified evaporator to provide uninterrupted heating.

3.2 Basic design of dual spray defrost

A total system refrigerant flux is the sum of the indoor and defrost bypass flow.

$$\dot{m}_{system} = \dot{m}_{Indoor} + \dot{m}_{Defrost,bypass}$$

Necessary total refrigerant flux can be calculated by system capacity and cycle parameters

$$Q_{system} = \dot{m}_{system} \times \Delta h$$

Δh is the difference of inlet from outlet enthalpy and function of saturated condensation pressure, temperature, super heat and sub cool of the condenser. When total mass flow is calculated, indoor mass flow can be determined by design point. For example, 50% of total mass flow means this can provide half the heating capacity during the defrost. After determined bypass mass flow, one can choose the valve orifice size which can pass a sufficient range of designed pressure conditions.
The total energy efficiency including defrost can be expressed as,

$$COP_{def} = \frac{Q_{sys} \cdot \alpha \cdot \alpha' + Q_{sys} \cdot \beta(2 - \alpha - \alpha')}{W_{sys} \cdot \alpha + W_{def}(1 - \alpha)}$$

Where α =nominal heating ratio, α' =heating ratio under non stop heating, β = heating supply ratio during defrost. A general air source heat pump system's $\alpha = 0.8 \sim 0.85$ and $\beta = zero$. For example, 37.5kW nominal heating capacity and 8.62kW power input model's nominal COP is 4.35. ($\alpha = 1, \alpha' = 1, \beta = 0$). But energy efficiency would be decreased inversely proportional to the heating ratio, α during the defrost condition ($\alpha < 1, \alpha' = 1, \beta = 0$) as shown in figure 3. The energy efficiency will be 15% decreased at α = 0.8.

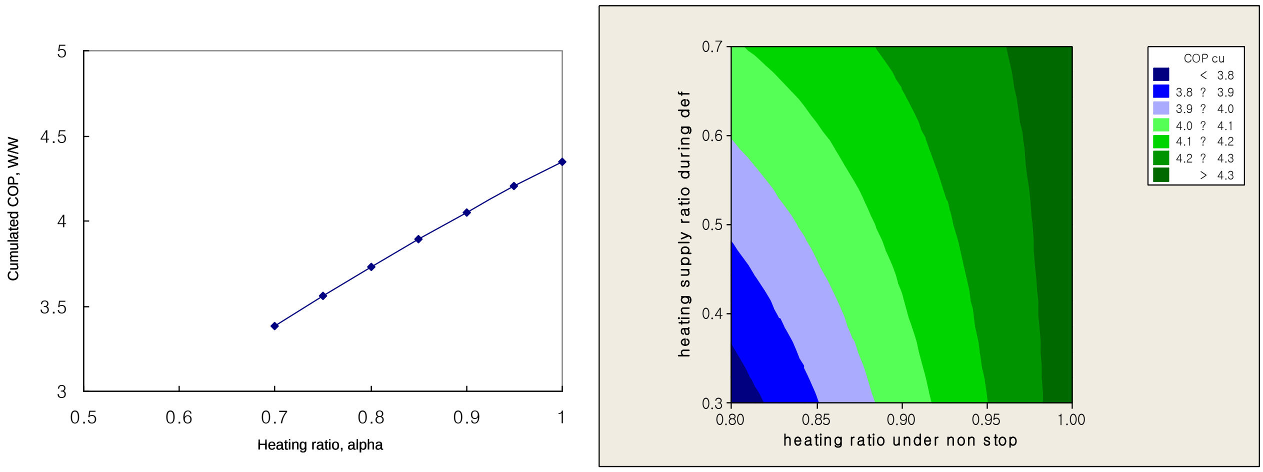


Figure 3. Defrost cycle diagram

On the other hand, in the view point of non stop heating ($\alpha = 1, \alpha' < 1, \beta \neq 0$), the energy efficiency will be a function of α' and β as shown in figure 3. The estimated efficiency of non stop heating was shown in figure 3 right. The α' and β were increased along with the total efficiency. Assuming that β is 0.5, the non stop heat pump can provide 50% of nominal heating during the frost with the same efficiency or higher under the same heating ratio ($\alpha = \alpha'$ =0.8).

3.3 The evaluation factors of continuous heating

There are some indexes to evaluate the durability of continuous heating performance. Figure 4 shows normal and abnormal defrost cycle. (a) is the general cycle diagram of the reverse defrost cycle and (b), (c) are bad examples for continuous heating. The definition of theta (θ) is the slope of the same event during the cycle. For example, as in figure 4, the slope of the defrost starting point is a very good choice. If θ has a negative number that means the cycle will collapse gradually and the heating capacity also as shown in (b). The other index τ is the ratio of heating operation. If τ is less than one that means the defrost period will occur too often and the cumulated heating capacity could decrease as shown in (c). So θ must be greater than zero and τ must be greater than one to maintain the steady heating cycle.

$$\tau_1 = t_2 / t_1,\ \tau_2 = t_3 / t_2,\ \cdots$$

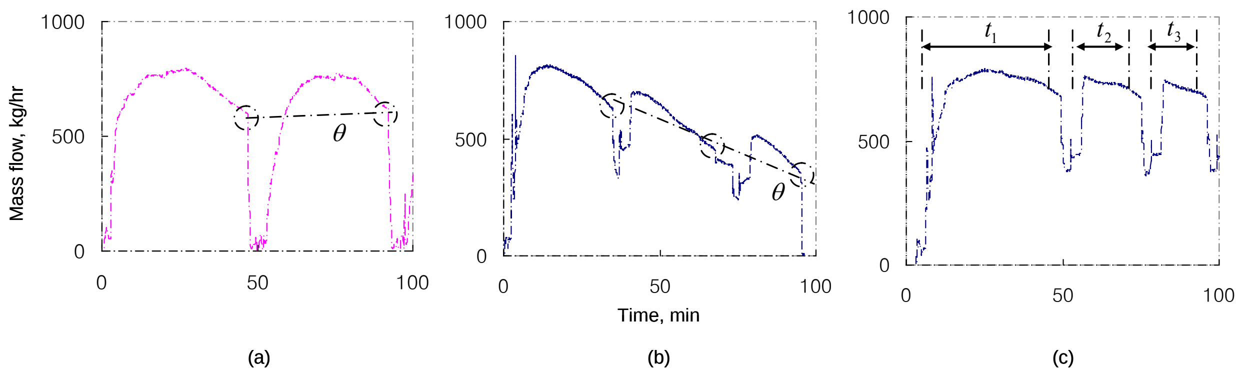


Figure 4. Defrost cycle diagram

The index of each cycle shown in figure 4 is (a)t (b) $\theta : -6.31, \tau : 1.02$ (c) $\theta : 0.24,\ \tau : 0.71$. In conclusion, this index should be fully considered before the evaluation of continuous heating.

4. Measurement Set Up

The tested heat pump has a 33.5.kW nominal cooling and 37.5kW nominal heating capacity (12hp). The nominal power input is 9.11kW for cooling and 8.62kW for heating. The coefficient of performance (COP) of the tested heat pump is 3.68 for cooling and 4.35 for heating. As shown in Fig.1, the set has two scroll type compressors which are composed of one inverter and one constant speed type. A wide louver fin type heat exchanger, two electronic expansion valves, an accumulator, a reverse valve, two solenoid valves control the dual spray hot gas flow. Four cassette type indoor units, each has 10kW nominal heating capacity, were connected. Each pipe length was 30m and total was 150m. The outdoor test condition was 2℃ dry-bulb and 1℃ wet-bulb temperature and indoor was 20℃ dry-bulb and 15℃ wet-bulb temperature. All tests have been progressed with psychrometric type calorimeter and meets with ISO standards.

5. Test Results

Figure 5 shows the heating capacity results between a common reverse cycle and the dual spray hot gas defrosting that we designed. The instant COP results are shown in figure 6 also. A reverse cycle defrosting method should shut down the indoor heating periodically to defrost. The designed dual spray hot gas method could provide 50% of nominal heating during defrost. So, total heating capacity increased by 17% compared to the reverse cycle defrosting as shown in figure 7. There were two reverse cycle defrosting and four hot gas defrosting over approximately 4 hours. The index noted was $\theta : 0.24,\ \tau : 0.96$ this means the non stop heating cycle would remain stable. As we have seen from figure 5 and 6, there were more defrost operations using dual hot gas spray compared to reverse cycle defrost.

.

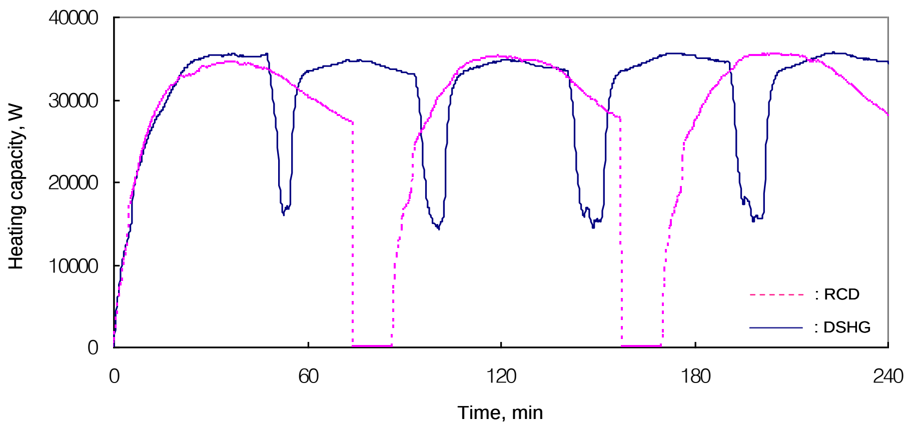


Figure 5. Heating capacity results

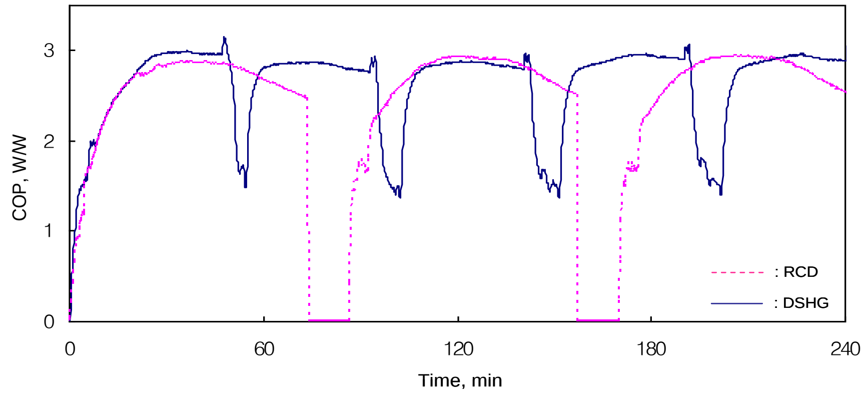


Figure 6. Instant COP Results

The hot gas method takes a long time to remove frost with a relatively low defrost heat because it shares heat energy with the defrost and indoor heating supply. Therefore, to use the hot gas method, earlier stage defrost is required before a full growth of frost and that is why more hot gas defrost frequency appears under the same conditions. The defrost starting and ending standards should be considered differently with this concept of earlier stage defrost. The cumulated performance indicators are shown in figure 7. The slope of the graph was almost the same between the two methods but the slope of the reverse cycle defrosting was zero during defrost because of the indoor heating interruption. On the other hand, the slope of the hot gas defrosting that was designed to supply 50% of nominal heating capacity during defrost was uniformed without variations. The cumulated performance of dual hot gas defrosting was increased by 17% compared to the reverse cycle defrosting during 4 hours. The cumulated power input was increased by 7.8% in the same mechanism. So, total cumulated energy efficiency was increased by 8% and compared with using an electronic heater that covered the lack of heating capacity, total efficiency was increased by 27% as shown in figure 8.

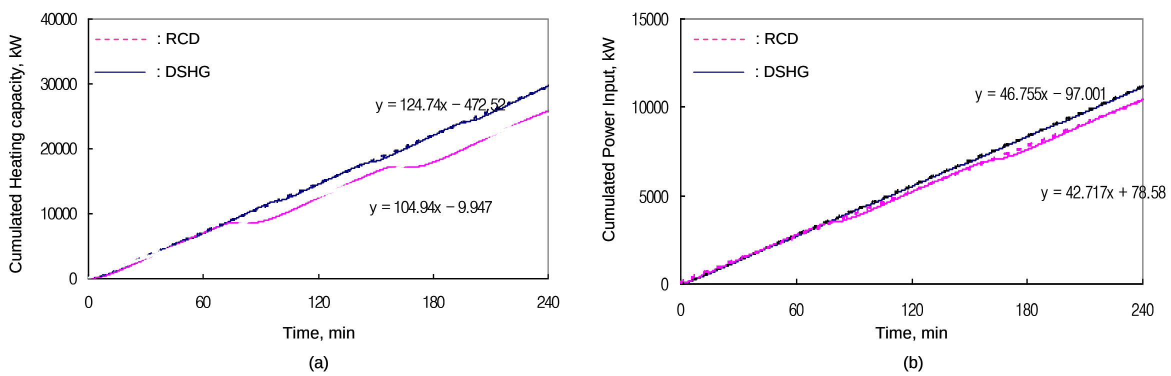
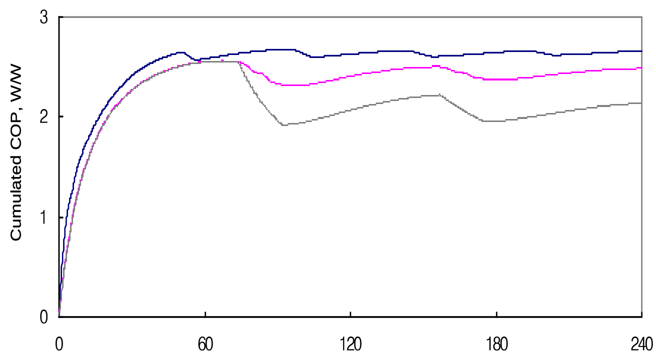


Figure 7. Cumulated Performance Results (a) capacity (b) power input



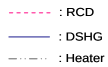


Figure 8. Cumulated COP Results

Figure 9 shows the photograph of dual hot gas spray defrost. When heat exchanger frost has grown and the signal has reached the designed condition, one-side defrosting begins. Generally, upper side defrosting should be started first because cold water that has been melted from the upper side heat exchanger possibly freezes again at the lower side. But the repeat of upper side defrosting can have deleterious effects on the lower side heat exchanger such as causing frost to remain on the lower side. In some cases, lower side defrosting should be started first as show in figure 9 b. In this situation, an outlet temperature drop of the indoor unit is inevitable because the designed indoor side refrigerant mass flow is about 50% of nominal. So, reduction of the indoor fan RPM is needed to minimize the outlet temperature drop during the hot gas defrost. Using the hot gas method, the time required to finish the defrost was about 10 minutes while the reverse cycle defrost was about 5 minutes with a view point of four way valve switching. But in case of a reverse cycle defrost, an interruption of heating occurs and also requires a period of time to reheat the cooled pipe of the indoor unit after defrosting. So, from a user's view point, total defrosting time will be about 15 minutes in substance and this can be another benefit of dual hot gas spray defrosting.

a. Defrost start   b. Half progress   c. Defrost ending

Figure 9. Dual spray defrost results

6. Conclusions

In this study, the newly designed dual hot gas spray defrosting method was examined and the defrost performances were compared to traditional reverse cycle defrosting method. The results can be summarized as follows:

1) A simple and low cost dual hot gas defrosting cycle structure was introduced and the most effective bypassed hot gas flow rate achieved was 50% of the total refrigerant flow rate during the defrost.

2) The total heating capacity was increased by 17% and the input power was increased by 7.8% over four tested hours. Finally, the total energy efficiency was increased by 8% compared to reverse cycle defrosting.

3) The total efficiency would be increased by 27% compared with using an electronic heater that covered the lack of heating capacity under the reverse cycle defrosting method.

References

[1] S.W Kim*, S.K Oh, B.Y Jung. *Building Multi Air Conditioner with higher efficiency and fault detection function*, 2008. International Refrigeration and Air Conditioning Conference at Purdue, July 14-17. 2435

[2] Tolga N. Aynur, Yunho Hwang*, Reinhard Radermacher. *Integration of variable refrigerant flow and heat pump desiccant systems for the heating season*, 2010. Energy and Buildings 42 468-476

[3] Yi-guang Chen*, Xian-min Guo. *Dynamic defrosting characteristics of air source heat pump and effects of outdoor air parameters on defrost cycle performance*, 2009. Applied Thermal Engineering 29 2701-2707

[4] Dong Huang*, Quanxu Li, Xiuling Yuan. *Comparison between hot-gas bypass defrosting and reverse-cycle defrosting method on an air-to-water heat pump* , 2009. Applied Energy 86 1697-1703

[5] Wang Zhiyi*, Wang Xinmin, Dong Zhiming. *Defrost improvement by heat pump refrigerant charge compensating* , 2008. Applied Energy 85 1050-1059

[6] K.M Kwak, C.H Bai*. *A study on the performance enhancement of heat pump using electric heater under the frosting condition: Heat pump under frosting condition*, 2010. Applied Thermal Engineering 30 539-543

[7] KS B ISO 15042, Multiple split-system air-conditioners and heat air-to-air pumps testing and rating for performance, 2006.

Energy-efficient heat pump driers – European experiences and efforts in the USA and Canada

Rita Werle, Eric Bush, Barbara Josephy, Jürg Nipkow

Topten International Services

Chris Granda

Grasteu Associates

Abstract

The use of clothes driers[1] is becoming more and more popular. As the penetration of electrically powered clothes driers increases in European homes, associated electricity consumption will increase considerably. However, energy efficient heat pump clothes driers consume only about half the electricity of conventional driers. The recent market success of this new technology should help to contribute to energy savings in Europe.

Only heat pump clothes driers are currently able to qualify for an "A" rating under the EU energy label. More than 34 models under 15 brands are currently offered on the European market for residential and semi-professional use and most of them are significantly more efficient than the actual "A" rating requirements. The sales share of all new clothes driers that have heat pump technology is highest in Switzerland (24.5% in 2009), but also substantial in Germany and Italy. Based on this success, the Swiss government will require all clothes driers sold in Switzerland to carry the "A" rating starting in 2012, effectively banning conventional driers. This successful market introduction and progress towards market transformation has been strongly supported by Topten (www.topten.eu) and its partners.

Over the past 15 years little attention has been paid to clothes drier efficiency in Canada and the USA. The Super Efficient Dryer Initiative SEDI was recently formed to learn from the European experience and to bring together energy efficiency program providers, drier manufacturers and governments to support large improvements in North American drier energy efficiency. SEDI's goal is to build a consensus around a target efficiency level for a super efficient drier and create the market conditions to support the introduction of new technologies and products. SEDI is not focused on a specific new technology, but SEDI stakeholders are studying the European experience to understand how heat pump technology conquered some national markets in Europe. First tests of European heat pump clothes driers have been undertaken to current US efficiency test standards.

Any successful super efficient drier for North America must be designed for the local market, and laundry habits. SEDI must also successfully facilitate the support of leading manufacturers and the ENERGY STAR appliance efficiency labeling program (there is currently no ENERGY STAR label for driers).

Introduction

The most ecological way of drying clothes is to hang them under the sun in fresh warm air. However, due to different reasons such as climate conditions, air pollution, limited space in small urban flats and less time for doing the laundry with more women going to work, the use of tumble clothes driers has gathered ground.

A domestic tumble clothes drier (in the following drier) is "an appliance in which textiles are dried by tumbling in a rotating drum, through which heated air is passed" [1]. In North America (USA and Canada) it is referred to as a clothes dryer. There are two main types of driers: 1) air vented driers

---

[1] The authors use in this paper the spelling „drier" as used in the European regulations and as opposed to the American spelling "dryer".

and 2) condenser driers. Air vented driers draw in fresh air and exhaust moist air into the room or through a vent to the outside. Condenser driers remove moisture from the air used for drying with a heat exchanger and collect the water as a liquid.

Currently the most efficient driers are condenser driers with heat pump technology. They use about 50% less energy than conventional condenser driers and are currently the only type of drier that qualifies for the class A European energy label (see Regulations in place: energy label). Vented driers are slightly more efficient than conventional condenser driers, except that venting the air used for drying to the outside may waste additional heating or cooling energy. A drier's energy consumption in practical use also depends on the spin-drying efficiency of the washing machine: if clothes are less wet when they exit the washing machine, there is less to be done by the drier [2].

Topten is an independent, internet-based platform fostering the introduction and penetration of the most energy efficient appliances – including driers - worldwide.

Europe

Market: stock and sales

The stock of driers in the European Union (EU) was estimated at 41 million units in 2000. An increase of over 20 million units was estimated by 2010 (see Figure 1).

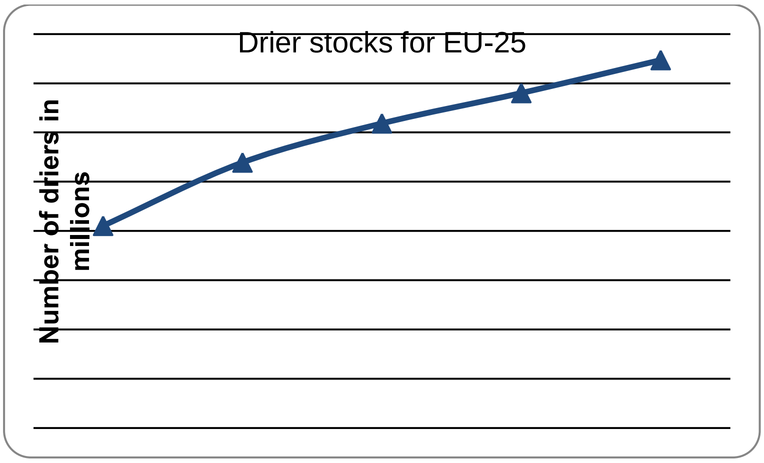


Figure 1. Drier stock development in the EU-25
Source: [3]

Within the European stock, the share of the ten new Member States[2] is expected to grow from 0.3% in 2000 to 6% in 2020 [3]. This shows that there are significant differences in the penetration of driers between East and West. This also applies for the North-South relation. To give an example, the number of driers sold in a year is about the same in Italy as in Switzerland [4], although the population of the two countries differs significantly (in 2009: 60 million and 8 million respectively) [5].

In 2007, more than 3.8 million tumble driers were sold Europe-wide, of which 93% were electrically heated. The share of condenser driers was estimated to 60% in 2007. Industry experts confirmed that sales have shifted towards condenser driers from air vented driers over time. A trend of increasing size has also been observed. The market has moved from driers with an average capacity of 4.5 to 5 kg in 2002 to a loading capacity between 5.5 kg and 6 kg in 2005 and in particular between 6.5 kg and 7 kg in the years after [3].

In 2005, 90% of driers sold on the European market were of energy efficiency class C [3] (see Regulations in place: energy label). In 2008, the market share for class A models was highest in Switzerland, Italy and Germany respectively (see Figure 2). By 2010, the class A market share rose sharply to over 30% in Switzerland and Italy and to over 20% in Germany according to expert opinions. In other European countries the class A market share remained low.

[2] Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, Slovakia.

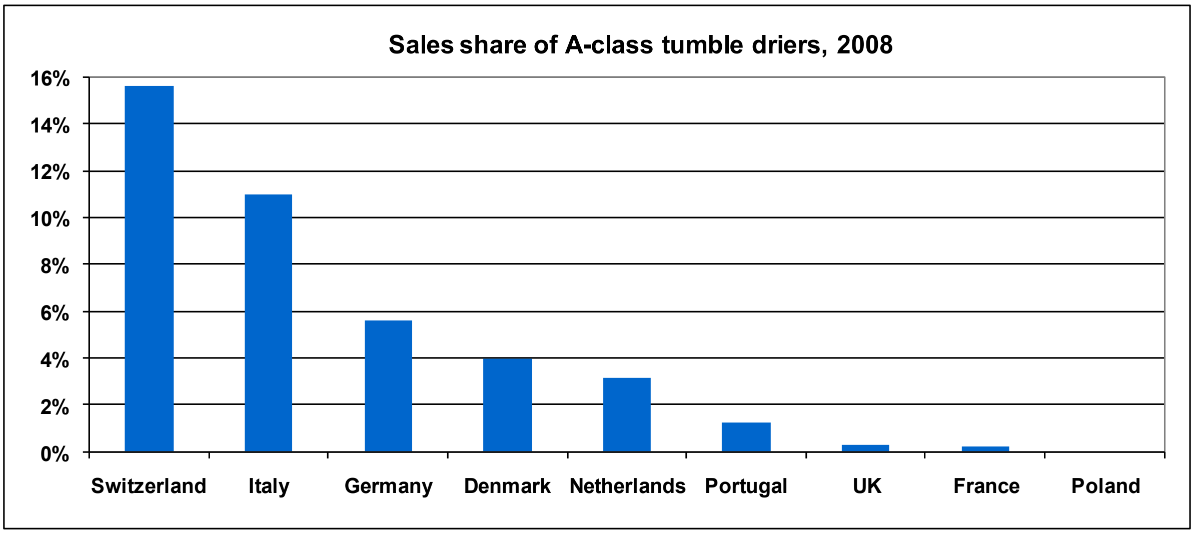


Figure 2. Sales share of class A models in 9 European countries in 2008
Source: [4]

Regulations in place: energy label

In 1995, the European Commission decided to introduce an energy label for tumble driers (Commission Directive 95/13/EC) [9]. The classification ranges from A to G (see Table 1).

Table 1. Energy efficiency class scheme for condenser driers

Energy label	Energy efficiency class	Energy consumption (C) in kWh/kg laundry* based on 60% initial moisture
	A	C ≤ 0.48
	B	0.48 < C ≤ 0.56
	C	0.56 < C ≤ 0.64
	D	0.64 < C ≤ 0.72
	E	0.72 < C ≤ 0.80
	F	0.80 < C ≤ 0.88
	G	C > 0.88

*According to test standard DIN EN 61121:2005 (based on 60% initial moisture). The Commission Directive 95/13/EC is based on 70% initial moisture.

Heat pump driers are the only technology to meet the class A requirement. The best heat pump models consume about 0.23 kWh/kg laundry, while the least efficient about 0.4 kWh/kg laundry (both at 60% initial moisture). Thus, heat pump driers not only meet the class A requirement but the best models exceed it by far. Although choosing between a class A and a class B model does not suggest much difference in efficiency for a user, there is a 50% efficiency gap between a typical heat pump drier and a conventional class B condenser drier [10]. Clearly, the energy label needs revision to better reflect the recent technological developments.

Switzerland: setting minimum energy performance standards to ban inefficient driers

Topten

Switzerland is the cradle of Topten, an initiative which aims at the acceleration of market transformation towards efficient energy-using products. Topten offers a website where a selection of the most efficient household appliances, office equipment, consumer electronics, building components, lamps and cars is listed, creating a dynamic benchmark for the most efficient technologies.

The first Topten site appeared in Switzerland in 2000 (www.topten.ch). Since then it has travelled the world and is online in 16 European countries (Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Italy, Luxemburg, Netherlands, Norway, Poland, Portugal, Romania, Spain and Switzerland), China (www.top10.cn) and the USA (www.toptenusa.org).

On www.topten.eu Topten presents the "Best Products of Europe".

Brand	V-ZUG	GEHRIG	SIBIR	Miele	FUST	V-ZUG	Bauknecht	SIBIR	GEHRIG	Blomberg	Inefficient model
Model	Adora TL WP	WT-TL WP 958	WT-TL WP 958 Swiss	T 86-27 WP / T 86-28 WP	ADORA 599TW	Adora TSL WP	TRW 6060	WT TSL WP Swiss	WT-TSL WP 959	TKF-1350 A	
List price €	2313	2313	2313	2434	1995	2625	2625	2562	2562	1744	1406
Electricity costs (€ 15 years)	585	585	585	675	720	720	720	720	720	742	1575
Capacity (kg)	6	6	6	6	6	6	6	6	6	6	5
Drying time (min)	120	120	120	104	90	90	90	90	90	120	90
Energy class	A	A	A	A	A	A	A	A	A	A	C
Energy Consumption (kWh/kg laundry)	0.26	0.26	0.26	0.30	0.32	0.32	0.32	0.32	0.32	0.33	0.70
Countries available	AT BE CH DE FR LU NL UK	CH	CH	NO, HR, EU without CY,MT,LT,LV,EE, UK	CH	BE CH DE FR IE LU NL UK	CH	CH	CH	CH CZ DE	

Figure 3. Snapshot of the most efficient driers on the European market on www.topten.eu
Snapshot made on 27 April 2011, driers for residential use, 6 kg capacity, energy consumption as declared at 60% initial moisture (according to test standard DIN EN 61121:2005).

Topten also provides recommendations for consumers on optimal product use. In the case of driers, the first advice is to dry clothes on a clothesline under the sun, if this is possible.[3] Besides user recommendations, Topten also formulates recommendations for policy makers.

Topten together with the Swiss Agency for Efficient Energy Use (S.A.F.E.) had a key role in achieving the market breakthrough of heat pump driers in Switzerland.

What is the recipe for success?

In 2003, Topten undertook the first tests of heat pump driers available on the Swiss market. Based on real-use feedback, Topten formulated user recommendations for driers. In 2003, Topten convinced the city of Zurich to choose only heat pump driers for its housing projects. In 2006, Topten convinced the power utility of Zurich (EWZ Elektrizitätswerk der Stadt Zürich) to offer consumers a rebate of up to EUR 200 [6] upon purchasing a heat pump drier. Since 2007, several other Swiss utilities and communities have launched rebate programs for heat pump driers [7].

As a result of these efforts, the market share of heat pump driers in Switzerland constantly increased, reaching 24.5% by 2009 (see Figure 4). Experts estimate the market share for 2010 to over 30%.

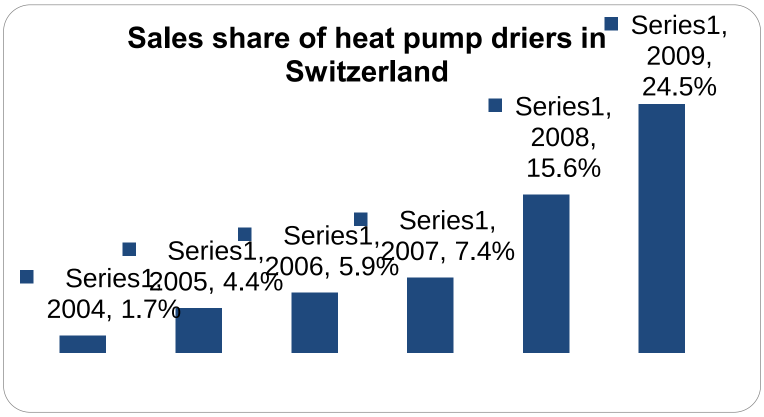


Figure 4. Sales share of class A driers sold in Switzerland
Source: Swiss Association of the Domestic Electrical Appliances Industry FEA

[3] During heating periods, it can be more energy-efficient to use a heat pump drier than to hang up clothes in the flat. See: Ina Rüdenauer, Carl-Otto Gensch, Ran Liu. *Vergleich der Umweltauswirkungen und Kosten verschiedener Wäsche-trocknungssysteme*. 17. June 2008. www.oeko.de

Topten estimated the savings potential at 400 GWh/year, if all driers in Switzerland were replaced by class A driers [8]. Observing market developments and aiming to realize this potential, Topten, S.A.F.E. and Swiss ecological and consumer organisations had advocated setting minimum energy performance standards (MEPS) for heat pump driers. In 2009, the time was ripe. Swiss policy makers decided to ban all drier models below class A from the Swiss market, starting in 2012. From then on, only class A (heat pump) driers can be sold in Switzerland.

Economic analysis of heat pump driers listed on Topten

The first heat pump drier appeared on www.topten.ch in 2000.[4] The number of available models expanded continuously to three in 2007 and eventually to 33 in 2011 (see Table 2). In 2010, the heat pump models on Topten were separated into two subcategories, based on their load capacity (6 kg and 7 kg load).

Figure 5 shows the evolution of purchase price for the heat pump driers listed on Topten from 2007 to 2011.[5]

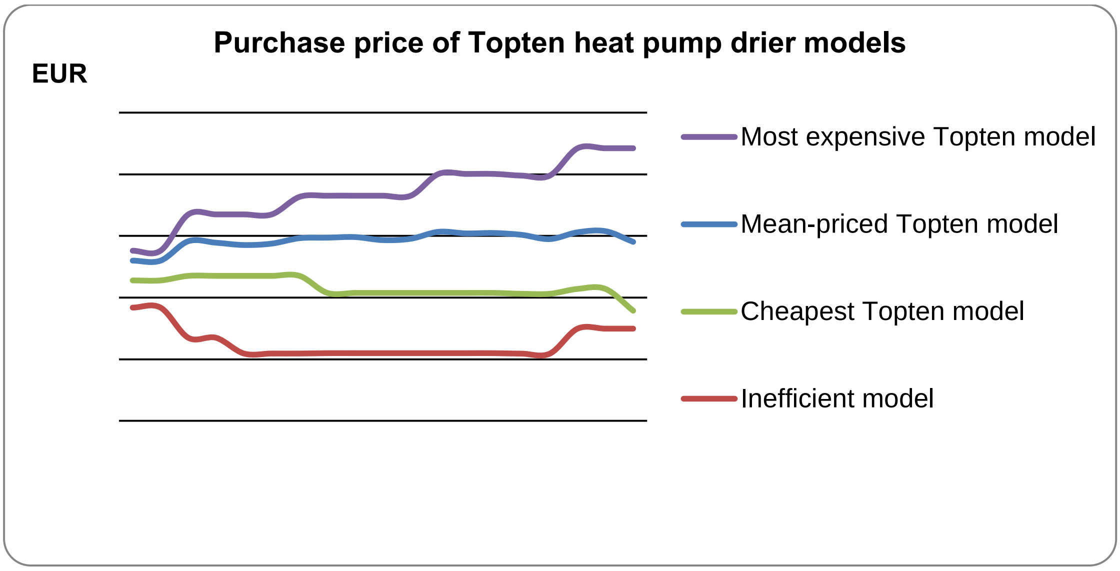


Figure 5. Purchase price of heat pump driers listed on www.topten.ch between 2007 - 2011
Prices are corrected for inflation.[6] Mean-priced Topten model stands for the average purchase price of all heat pump models listed on Topten. Inefficient model is an average class C condenser drier (as declared by the manufacturer) available on the market, used as a baseline for comparison.

The first heat pump drier to appear on Topten was available for EUR 1300. Figure 5 shows that the purchase price range of heat pump models became wider as more products entered the market.

Table 2. Number of heat pump models on www.topten.ch

	Jan 07	Jan 08	Mar 09	Jan 10	Jan 11
purchase price > EUR 1200	0	3	6	17	17
purchase price < EUR 1200	3	3	6	10	16
Total	**3**	**6**	**12**	**27**	**33**

The average purchase price of the listed models is about the same over time. A trend towards lower purchase prices was observed with a number of competing heat pump drier models and brands, such

[4] An AEG model.
[5] Time periods between the different data points are not equal. This is because Topten lists were updated each time a new model was available on the market. For 2011 there is one data point, for 2007 two, for 2008-2010 there are 4-7 data points per year.
[6] See all assumptions for calculation in Annex.

as a range of models offered by manufacturer AEG, priced around 1300 Euro in 2005 and around 1000 Euro by early 2011.

The average efficiency of the heat pump models on Topten was 0.38 in 2007 and 0.28 in 2011 (at 60% initial moisture).

In 2008, the market share of class A driers reached 15.6% in Switzerland. In 2010 Topten chose a more efficient class C model as a baseline for comparison, in accordance with the market developments.

The first heat pump models to offer automated condenser filter-cleaning are already available. This is a big comfort benefit for users, as they do not have to clean the (heat pump) filter manually anymore. Other features offered in high-end models include: low noise levels, extra short programs (e.g. 40 minutes for a 2 kg load), interior drum lighting, sensor drying (the drier automatically stops when a certain level of humidity is reached) and of course, very gentle care of clothes. All these benefits and features as well as best available technology components lead to higher purchase prices of these high-end models.

If a consumer decides on which drier to buy based on the life cycle costs (see Figure 6), it is evident that a cheap heat pump model is the most economical choice. The life cycle costs of a mean-priced heat pump model are still lower than - but closer to – the life cycle costs of an inefficient model. Targeted information is certainly helpful to convince the consumer for the more efficient model.

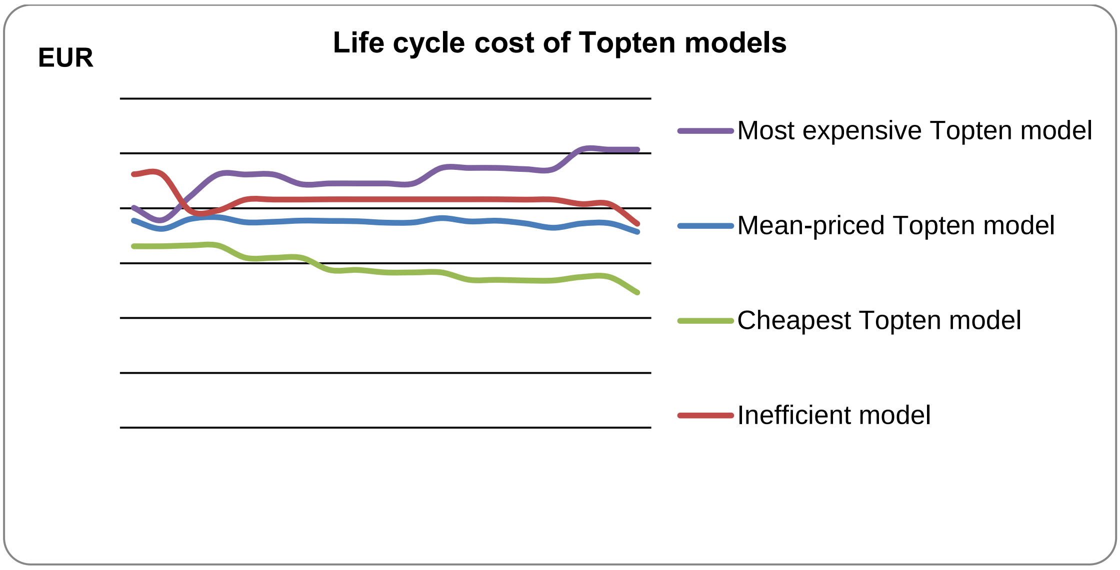


Figure 6. Life cycle cost of heat pump driers listed on www.topten.ch between 2007 - 2011
Assumptions: 1000 kg laundry dried per year, life span 15 years, electricity price 0.15 EUR/kWh[7].

A cost gap remains between inefficient and high-end models. Consumers are more likely to purchase the more expensive model if (i) they have a great appreciation for high-end quality or (ii) if financial contribution is offered. If a single subsidy is provided for class A models without regard to the price of the drier, it will not interfere with manufacturers' pricing strategy, or consumers' perception of value.

Coming regulations: no Eco-design requirements, revised energy label

In 2005, the EU established a framework for setting Eco-design requirements for energy-using products (Directive 2005/32/EC) [11]. The aim of the directive was to set minimum energy performance standards for such products taking into account their environmental impacts throughout their whole life cycle. In 2009, with the recast version Directive 2009/125/EC [12] it was expanded to energy-related products.

[7] Electricity prices for EU-27, first semester/second semester in EUR/kWh: 2007: n.a. / 0.156; 2008: 0.158 / 0.166; 2009: 0.164 / 0.164; 2010: 0.168 / n.a. Source: Eurostat http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_204&lang=en.

In Lot 16, tumble driers are assessed. The preparatory study[8] was completed in March 2009 and analysed the technical, environmental and economic aspects of driers. Based on this, a proposal for a draft regulation was made in June 2010, at the last meeting of the Consultation Forum. According to this proposal [1]:

1. No Eco-design requirements shall be set for tumble driers.

2. The energy label shall be revised.

As for point 1:

The reasoning behind the proposed (non-)action is that the following conditions of Directive 2009/125/EC [12] are not met:

- "the product shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs" (Article 15(2) (c));

- “Concerning energy consumption in use, the level of energy efficiency or consumption must be set aiming at the life cycle cost minimum to end-users for representative product models” (fifth paragraph of point 1 of Annex II).

The proposed draft acknowledges that heat pump driers are gaining market share. With the revision of the energy label, it anticipates accelerated market transformation towards more efficient driers which is likely “to lead to a significant fall of their price” [1]. The adoption of Eco-design measures at a later stage in time is left open.

As for point 2:

The revision of the energy label includes the following:

- including gas fired household tumble driers;

- one common energy classification for electric air-vented, gas air-vented or electric condenser driers, to allow easy comparison for users;

- adding program time and condensation efficiency for condenser driers on the label;

- adding classes A+, A++ and A+++. This would allow the take up of more efficient appliances on the market. The best driers currently on the market would reach class A++ in this scheme.

- revised calculation method for the energy efficiency index, being the basis of the labelling.

The revised calculation method for the energy efficiency index would align to the revised methodology of the energy labeling of household washing machines [13] and dishwashers [14]. The proposed method would relate to the annual energy consumption (and no longer to kWh/kg laundry), based on a fixed amount of drying cycles per year with mixed load and low power modes. The efficiency class would be a function of the rated capacity of the drier.

Policy recommendations for the heat pump drier market breakthrough

Policy measures should stimulate and foster market transformation, marking the path. Therefore, technological change should be supported by adequate policies, instead of lagging behind the actual market developments.

Topten agrees that the energy label is a very powerful tool for pulling the European market towards more energy efficient appliances. It certainly should anticipate the arrival of new technologies.

[8] Carried out by Ecobilan, PricewaterhouseCoopers’ Centre of Excellence, in cooperation with Conception Développement Durable Environnement (CODDE) and KERP Center of Excellence in Electronics & Environment, for the European Commission.

However, instead of introducing three new classes (A+ to A+++), Topten proposes the following scheme:

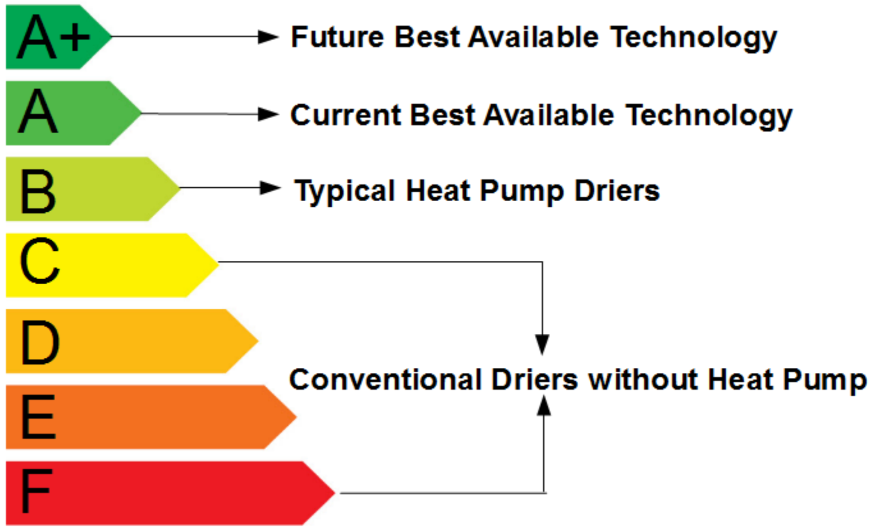


Figure 7. Energy label classification proposed by Topten

Today's Best Available Technology (the most efficient heat pump driers) shall fall into class A. A+ would be reserved for future Best Available Technology. Class B shall be reserved for heat pump driers only (typical, not the most efficient models). Conventional models without heat pump technology would fall into class C and below (being unable to reach class B). Class G would be banned from the market.

Topten strongly encourages the introduction of minimum energy performance standards MEPS. This could be done in two steps:

- Tier 1: banning the most inefficient products from the market.
- Tier 2: setting heat pump driers (class B in Figure 7) as MEPS with sufficient delay, with the option for revision - should pre-defined market shares not be met.

In addition, promotion, discount and rebate programs could help to bridge the purchase price gap between heat pump and conventional condenser driers.

Last but not least, consumers' awareness shall be raised with targeted information (e.g. on life cycle costing). Topten is an ideal platform for this activity.

To sum it up, Topten proposes to:

- Push the market with MEPS;
- Pull the market with the energy label, incentive programs and information campaigns.

United States of America (USA) and Canada

Market: stock and sales

There are more than 80 million residential electric driers in use in American and Canadian homes today. Tumble clothes driers are now approaching the penetration of washing machines in North America. Table 3 shows that residential drier penetration was already high in both Canada and the USA in 2007.

Electrically heated driers dominate in both countries, but more in Canada than in the USA, where a significant share of driers are heated with natural gas or propane. Also, while condensing driers are the dominant technology in Europe, almost all driers in Canada and the U.S. are non-condensing, vented models. Vented driers pull ambient air from inside the home, heat the air and use it to dry clothes, and then expel the hot moist air through a duct to outdoors.

Table 3. USA (2009) and Canada (2007) clothes drier stock

Market Penetration		**USA**	**Canada**	**Both**
Total households	million	113.6	12.9	126.5
Households with electric driers	%	63.2%	82.9%	65.2%
	million	71.8	10.7	82.5
Households with gas or propane driers	%	16.3%	4.9%	15.1%
	million	18.5	0.6	19.1
Households without driers	%	20.6%	11.6%	19.7%
	million	23.4	1.5	24.9

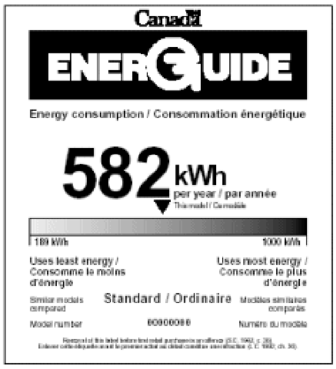
Source: Residential Energy Consumption Survey conducted by the U.S. Energy Information Agency http://www.eia.doe.gov/consumption/residential/data/2009 and data from the Natural Resources Canada Survey of Household Energy Use 2007
http://www.oee.rncan.gc.ca/publications/statistics/sheu07/pdf/sheu07.pdf
On average, one drier per household is assumed.

Annual sales of electric tumble driers in the USA and Canada are estimated to be in the range of 6 – 7 million units, based on Appliance Magazine's annual appliance industry snapshot [15] and the U.S. Department of Energy's technical assessment document for residential driers [16]. The average North American electric clothes drier has a service life of 12-17 years [15] [16].

Regulations in place

American and Canadian energy policy ignored clothes drier energy efficiency for many years because it was widely believed that not much could be done to improve efficiency. Starting in 1994 and 1995 respectively, the USA and Canada adopted the same minimum efficiency standards and energy efficiency test procedures for clothes driers. The minimum efficiency standard as of the publication of this paper is at 1.37 kilograms (3.01 pounds) of water removed per kilowatthour [17] – equivalent to 0.73 kWh per kg water removed - of electricity consumed. However, on January 6, 2011 the US Department of Energy issued a new energy efficiency test procedure for clothes dryers which should allow more accurate measurement of the energy use of modern clothes dryer models. On April 21, 2011 the US Department of Energy also issued a Direct Final Rule [18] for energy conservation standards for residential clothes dryers which will increase the minimum efficiency standard for electric clothes dryers by 24% to 1.7 kg (3.73 pounds) of water removed per kilowatthour – equivalent to 0.59 kWh per kg water removed - in 2014.

Canada requires that clothes driers carry the "EnerGuide" label showing relative energy efficiency. However, there is no requirement for US driers to carry an equivalent "Energy Guide" label. More importantly for both countries, the ENERGY STAR voluntary energy efficiency labelling program currently covers clothes washers but not driers. Therefore North American consumers today have little information upon which to base energy efficiency comparisons.



Savings potential

In 2010, Ecos Consulting, an American energy efficiency consulting firm, tested a popular model of heat pump clothes driers currently available on the European market using the US test procedure to establish a baseline for comparison of energy efficiency between European and North American driers. Ecos found that the European heat pump drier used 40-50% less energy than the average conventional North American vented tumble electric drier to dry the same load of laundry.

Ecos also found that there were significant differences in energy efficiency between clothes driers currently on the market in the USA. Table 4 shows the potential savings of the European heat pump clothes drier versus both the average conventional new U.S. drier ("Standard") and the best new conventional drier ("Higher Efficiency"). Both the "Standard" and "Higher Efficiency" driers are air vented models.

Table 4. Potential savings from heat pump clothes drier in the USA and Canada

European heat pump clothes drier compared to:		Standard	Higher Efficiency
Annual savings	kWh/year	462	332
Annual savings	USD/year	76	54
Lifetime savings*	kWh	6,926	4,984
Lifetime savings*	USD	1,136	817

*SEDI (Super-Efficient Dryer Initiative) analysis assuming an average drier lifespan of 15 years, and New Jersey average electricity price of USD 0.16 per kilowatthour.

Ecos Consulting also reported that the European heat pump drier cycle length was 110 to 122 minutes, compared to 23 to 59 minutes for the US driers. In Europe, heat pump driers compete with condensing electric resistance driers, which also tend to have longer drying cycle times. In addition, the length of the washing and drying cycles is about the same in Europe, while in the USA washing cycle times are also shorter. Canadians and Americans are accustomed to shorter drier cycles but it is not clear if this will present a barrier to adoption of heat pump drier technology.

Challenges

At this time, there are no heat pump clothes driers that are widely available to Canadian and American consumers. Other than the recent Ecos Consulting research discussed above, there is little data available on the actual energy consumption of clothes driers in the USA and Canada. North American consumers are used to clothes driers that are larger than typical European models, and are also used to shorter cycle times. Clothes washers and driers and electricity all tend to be less expensive in the USA and Canada than in Europe. These differences between the clothes drier markets, and the differences in the European and North American electricity distribution grid, require that manufacturers develop new, energy efficient driers for the USA and Canada. It will also be necessary to educate consumers on the benefits so that they will be willing to pay for more efficient clothes drier technology.

Policy change: first initiatives

There is a growing awareness of the European experience with heat pump clothes driers, and interest in exploring similar opportunities in Canada and the USA. In 2010 the US government also awarded funds to technology development firms and appliance manufacturers for the development of new super-efficient clothes driers. On January 6, 2011 the U.S. Department of Energy culminated a two-year review process and released updated drier energy efficiency test procedures. This is a critically important development that will allow an accurate assessment of the energy efficiency of driers now on the market, and of new products which may soon be introduced.

In 2009, the New Jersey Clean Energy Program awarded research funds that created the Super-Efficient Dryer Initiative (SEDI). During the summer of 2010 SEDI held meetings across the USA and Canada to support the development of super-efficient electric tumble clothes driers for the American and Canadian markets. SEDI is working with appliance manufacturers to draft voluntary technical specifications for efficient driers that could be the basis for energy efficiency program incentives, and also for a future ENERGY STAR for clothes driers program.

Goal

Because successful market transformation efforts have made refrigerators and clothes washers much more energy efficient, clothes driers are now one of the largest single electricity consuming appliances in American and Canadian homes (after heating and cooling equipment and lighting). Electric tumble clothes driers may account for 7-8% of all electricity usage in Canadian and American homes that have them[9].

---

[9] based on estimate 827 kWh average drier consumption, and average annual total consumption of 11,480 kWh per home in USA (2005 Residential Energy Consumption Survey http://www.eia.doe.gov/emeu/recs/recs2005/).

SEDI will work together with drier manufacturers, ENERGY STAR, U.S. and Canadian energy efficiency programs and TopTen USA [19] to develop common energy efficiency specifications, to support new, energy efficient driers in the market place with labelling and incentives, and to educate consumers.

Summary and conclusions

In Europe there is an increasing demand towards tumble clothes driers. North America has a high penetration of tumble clothes driers.

Heat pump driers are currently the most energy efficient driers, rapidly gaining market share in Europe. Switzerland has set minimum energy performance standards for driers at the current class A, effectively banning driers without heat pump technology from the market starting in 2012. Rising market share for heat pump driers has led to declining prices. Life cycle cost comparisons show that heat pump driers are cost-effective compared to conventional driers. Topten advocates the setting of minimum energy performance standards for heat pump driers all over Europe, subsidies and targeted information for consumers.

In North America first test results show the energy savings potential of heat pump driers. Challenges of their introduction on the market include consumer behavior (e.g. being used to shorter cycle times and larger loads) and education, as well as cheaper electricity prices. Changes in policy and support for innovation may lead to the introduction of new, more efficient driers in Canada and the USA soon. SEDI aims to stimulate this process.

Acknowledgements

The Topten project team gratefully acknowledges the financial support of:

- The European Commission's Intelligent Energy Europe Programme (http://ec.europa.eu/energy/intelligent/) which made it possible for Topten to be present in 16 European countries and continues to support the build-up in three more European countries (www.topten.eu).
- The European Climate Foundation (www.europeanclimate.org) who supports Topten in updating and expanding technical and policy analysis of the most energy-efficient products.
- WWF (www.wwf.org) who supports the build-up of Topten China (www.top10.cn) and supports other Topten projects in Hongkong, the USA (www.toptenusa.org) and Europe.
- The Swiss government: REPIC (Renewable Energy & Energy Efficiency Promotion in International Co-operation - www.repic.ch) and SECO (State Secretariat for Economic Affairs - www.seco.admin.ch) who supports the build-up of Topten China.

Grasteu Associates acknowledges the US Environmental Protection Agency for providing funding to Ecos Consulting to allow the testing of clothes dryers.

References

[1] *Working Document on the ecodesign and labelling of household tumble dryers*, Presented by the Directorate General for Energy for Consultation Forum on Friday 25 June 2010. Can be downloaded at: http://ec.europa.eu/energy/efficiency/ecodesign/forum_en.htm

[2] Barbara Josephy, Eric Bush, Jürg Nipkow, Sophie Attali, Rita Werle, Chris Granda. *Changing washing machines and driers: Let's have a look at the laundry room*. Paper for the 2011 Summer Study of the European Council for an Energy Efficient Economy. 6–11 June 2011 Belambra Presqu'île de Giens, France

[3] PricewaterhouseCoopers. *Ecodesign of Laundry Dryers. Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16*. Final Report March 2009. Can be downloaded at: www.ecodryers.org

[4] Sophie Attali, Eric Bush, Anette Michel. *Factors influencing the market penetration of energy efficient electrical appliances into national markets in Europe*. Report for Defra / the Market Transformation Programme by SoWATT and Bush Energie GmbH. Can be downloaded at: http://www.topten.eu/english/all_news.html and data from the Swiss Association of the Domestic Electrical Appliances Industry FEA

[5] http://data.worldbank.org/country

[6] www.ewz.ch consulted on 20 January 2011.

[7] Jürg Nipkow, Barbara Josephy, Eric Bush, Anette Michel. *Tumble Driers: Recommendations for policy design*. September 2010. Available at: www.topten.eu

[8] Conrad U. Brunner, Anette Michel, Jürg Nipkow, Barbara Josephy, Eric Bush, Sophie Attali. *Topten's success story number 1: The heat pump laundry dryer breakthrough*. Zürich, 17. August 2010. Topten internal paper.

[9] European Commission. Commission Directive 95/13/EC of 23 May 1995 implementing Council Directive 92/75/EEC with regard to energy labelling of household electric tumble dryers. http://ec.europa.eu/energy/efficiency/labelling/energy_labelling_en.htm

[10] Jürg Nipkow, Eric Bush. *Promotion of energy-efficient heat pump dryers*. Energy Efficiency in Domestic Appliances and Lighting Proceedings of the 5th International Conference EEDAL'09 16-18 June, Berlin, Germany, Volume 3, pages 1215-1225, EUR 24139 EN/1 – 2010.

[11] European Parliament and Council. Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32005L0032:EN:NOT

[12] European Parliament and Council. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast). Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:01:EN:HTML

[13] European Commission. Commission Delegated Regulation (EU) No 1061/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of household washing machines. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010R1061:EN:NOT

[14] European Commission. Commission Delegated Regulation (EU) No 1059/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of household dishwashers. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010R1059:EN:NOT

[15] Appliance Magazine. *31st Annual Portrait of the U.S. Appliance Industry*. September 2008, page 2.

[16] U.S. Department of Energy's technical assessment document for residential dryers, EERE-2007-BT-STD-0010 COMMENT 20.3. page 3-33.

[17] U.S. National Appliance Energy Conservation Act (NAECA). Available at: http://thomas.loc.gov/cgi-bin/bdquery/z?d100:sn00083:@@@L&summ2=m&

[18] U.S. Government, Federal Register / Vol. 76, No. 77 / Thursday, April 21, 2011 / Rules and Regulations page 22454

[19] www.toptenusa.org

Annex

Assumptions for the calculation of the purchase price of Swiss heat pump driers in EUR:

1. Prices have been corrected for base year 2007 with consumer price increase:

Year	Annual price increase (%)	Price index (basis year 2007)
2007		100.0
2008	2.4%	102.4
2009	-0.5%	101.9
2010	0.7%	102.6

Source: http://www.bfs.admin.ch/bfs/portal/de/index/themen/05/02/blank/key/jahresdurchschnitte.html

2. 30% off of list prices (except for cheap models) to account for Swiss pricing practices.

3. 70% of the corrected list prices, to account for the fact that prices in Switzerland are higher than in the surrounding countries.

OECD monthly comparative price levels:

Country	Comparative price level of Switzerland (CHF)	
	October 2008	October 2010
Austria	74	68
Belgium	78	72
France	77	71
Germany	75	68
Italy	76	70
Luxembourg	76	76
Netherlands	75	69
United Kingdom	71	60

The table shows how many Swiss francs (CHF) are needed in the countries listed to buy the same representative basket of consumer goods and services, which in Switzerland costs 100 CHF.
Source: http://stats.oecd.org/Index.aspx?DataSetCode=CPL and private communication with Anette Michel.

4. 1.5 EUR/CHF for the whole period. Foreign exchange rate fluctuations do not largely influence Swiss list prices but would influence EUR prices of this analysis.

Average exchange rates, calculated from the daily published reference exchange rates of the European Central Bank:

Year	EUR/CHF
2004	1.5438
2005	1.5483
2006	1.5729
2007	1.6427
2008	1.5874
2009	1.5100
2010	1.3803

Source:
http://www.bundesbank.de/statistik/statistik_zeitreihen.php?lang=de&open=devisen&func=row&tr=WJ5622

Methods for Optimization of Efficient Energy End-use in the Residential Built Environment

J.J. Bloem[1], H. Madsen[2], P. Bacher[2], H.A. Nielsen[3], S.B. Mortensen[3]

[1] European Commission, JRC – IE, RE-Unit, TP 450, I-21020 Ispra, Italy,

[2] IMM, Technical University of Denmark, DK-2800 Lyngby, Denmark

[3] ENFOR A/S, Lyngsø Allé 3, DK-2970 Hørsholm, Denmark

Abstract

Nowadays dynamic methods are recognized as tools for the optimization of efficient energy end-use. From one point of view this is due to the development of instruments that allow recording of high frequency observations through smart meters, while from energy policy point of view the requirement of reducing energy end-use in the residential sector is of high priority. Dynamic methodology for management and control at different levels in the energy supply and demand has become of the highest importance.

In residential buildings about 2/3 of the energy is consumed for space heating and cooling, while the remaining 1/3 is consumed by appliances and light. In new and renovated buildings the tendency is an increase in electricity consumption for comfort in the indoor environment (Bloem and Atanasiu, 2009). In particular the energy specific Directives require technologies such as renewable energies and innovative but energy complex building components and systems that can deal with high frequency demand and supply of energy. The recast of the Energy Performance for Buildings Directive (2010/31/EU) requests for nearly-zero energy buildings (annual energy consumption) that can be fulfilled when overall building energy performance is improved and storage technology is applied. It is already anticipated that the electricity grid cannot manage this unless proper information and computation technology is put in place. Furthermore, for improvement of building energy performance and measuring effectiveness of policies, thermal characterisation of buildings is a requisite.

Storage of energy, both thermal and electrical, requires proper management to achieve the highest efficiency of energy use corresponding to distributed control. It should be noted that near zero energy buildings are based on annual consumption whereas the management tends to high frequency control of distributed energy supply and demand. The functionality of the building in the energy network has to be and will change in the future when all energy related Directives (such as 2006/32/EC, 2009/28/EC) have been implemented. Smart meters and intelligent metering environments are therefore becoming increasingly popular (COM(2011) 202). Today smart meters are mostly used only for frequent reading of the energy consumption and could well serve the energy labelling of buildings. It is however, clear that these data contain highly valuable information which, together with appropriate statistical methods for data analysis, can be used to manage energy supply and consumption at utility as well as decentralized (domestic) level. Future domestic appliances are therefore likely to be equipped with communication technology to the end-user as well as to the energy utility (management). This will include the management of peak supply, due to the variable renewable energy resources like solar and wind power on the grid, as well as the peak demand, due to appliances such as air conditioners, heat pumps and electric vehicles.

Methodologies for the assessment of the energy related parameters will be incorporated in the instruments for metering, communication and control of decentralized energy supply and demand.

The paper presents one available methodology and results from the analysis of energy consumption in single family houses. This methodology will enable automatic energy labelling.

Introduction

Increasing interest in research in energy technologies result in the rapid transformation into a sustainable and secure energy future for Europe, together with further advancements in information technology (Internet, fast computers and portable platforms), herald many opportunities for European research, and building and appliance industry. The development of intelligent buildings fully integrated in the energy system of 2020 requires the application of dynamic methods in order to make use of the available energy resources with highest efficiency for a sustained living and working environment.

Dynamic analysis methods are techniques to analyze time series of data related to a dynamic process and to identify typical parameters of the physical process for evaluation. Dynamic methods take into account the aspect of time whereas a static analysis method does not. By dynamic evaluation techniques (parameter identification) dynamic effects due to accumulation of heat in the building interior construction, envelope and equipment are properly taken into account. In general, parameter identification is needed to be able to derive the steady state properties from a relative short period with dynamic (e.g. fluctuating outdoor) conditions. In general dynamic methods can deal with different frequency ranges at the same moment, e.g. the evaluation of yearly (overall energy evaluation), monthly (standardized energy calculation for building energy performance assessment), daily (impact of solar energy), hourly up to minute occurrences of events from appliances. The application of system identification techniques to the energy performance assessment of buildings and building components requires a high level of knowledge of physical and mathematical processes. This factor, combined with the quality of the data from smart meters, the description of the monitoring, together with the experience of the user of the analysis software itself, can produce varying results from different users when applying different models and software packages. To apply dynamic methods successfully requires a skill.

The present application of statistical methods for evaluation is gradually moving from monthly, to daily, and to observations with a higher frequency. During the next 5 to 10 years dynamic calculation techniques will become more and more common than today. Topics for building energy performance assessment that require the application of dynamic techniques:

- Intelligent management for energy service companies (ESCO) and end-user.
- ICT for demand management and awareness to the end-user.
- Distributed energy storage (it is expected that feed-in tariffs will disappear) and new energy market models will appear.
- Fuel shift; Renewable electricity for Domestic Hot Water and/or space heating and cooling.
- Innovative techniques for appliances management, like load shift.
- Forecasting of solar and wind power (utility and private).

The application of dynamic methods has been made possible by the fast development of information and communication technology (ICT) (ICT-REEB, 2009). Fast computers running intelligent software programs can deal with enormous amount of data and make information available to optimize processes through improved control and communication. In the energy management of buildings it opens enormous potential of energy savings and improved efficiency.

ICT can be instrumental in achieving more efficient use of energy through, modelling for simulation and evaluation, monitoring of performance and visualization tools that are needed to facilitate a ”whole building energy assessment approach” to both building designers and energy managers.

The integration of variable renewable energy resources like wind and solar power is facilitated by proper forecasting techniques (Nielsen et al., 2002). The over-production of electricity should be used or stored and the domestic sector can provide some release. In Denmark the over-production has been reached at about 20% of wind power of the electricity mix (Costa et al., 2008). This shows the need for intelligent management and probably the facilitation of intermittent changing the fuel from gas to electricity for appliances like sanitary hot water, space heating (Winter) and cooling (Summer). This would require the development of innovative gas boiler appliances and requires the intelligent control by the utility over some dedicated domestic appliances or a regulation via price signals. However the real fear of power providers is not the peak supply but the increasing chance of peak demand by appliances such as heat pumps and in the future electric vehicles (RE&EV 2010).

One way to go might be when distributed electricity storage becomes an integral part of the building energy system. A battery package (like 2 kWh for an average residential house consuming 4 to 5 MWh annually) can bring many advantages to both end-users as provider. The peak demand caused by appliances that require high power for a short moment, like washing machines and electric hot water appliances, can be reduced significantly and the energy flow can be more balanced and much better managed by the utility. Integration of photovoltaic in the built environment might probably go into this direction also requiring 400 Wp without the need for a second counter. The advantage for the end-user will be that efficient use of energy and resources is dealt with by the provider and in return the quality of the energy system is increased. When the capacity of the battery pack is dimensioned well the utility can store over-production of wind and solar power and reduce the risk of peak power demand and fall-out. Energy providers are studying at present the development of new market models that fulfil this need.

Smart and Intelligent Metering Environments

Soon energy meters will allow for simultaneous and frequent readings of power, heat and water consumption also in family houses, and the readings will in most cases be transferred by the IP protocol to a central facility for energy managements. Energy meters give possibilities for obtaining time series of actual energy consumption in households with readings say every 5 to 10 minutes. At the same time meteorological services will facilitate possibilities for obtaining local time series of relevant and local meteorological parameters. To clarify the difference between smart and intelligent metering environments the following brief definitions can be applied: Smart meters are, compared to traditional electricity, water or gas meters, taking readings in more and regular detail and communicate them electronically through some network to the utility (and end-user) for monitoring and billing purposes (often referred as automated meter reading). Intelligent metering environments can in addition, analyze these observations, identify characteristics and make decisions aiming to improve further the optimization of energy efficiency. The utility as well as the end-user can communicate with the intelligent meter also (two-way communication). Readings from smart meters might be analyzed on a central server and so become a part of an intelligent metering environment, for example for district heating management or to energy service companies to manage whole building energy use.

EU legislation on buildings has also sought to pave the way for the introduction of intelligent metering systems. In April 2009, the European Parliament voted to add a provision to the Energy Performance of Buildings Directive that will require the installation of smart meters by default in all new buildings as well as when major renovating is done (EU (2010); article 8.2).

In the near future these time series will provide the background for using the developed methods for:

1. Improved control of the energy supply to buildings, e.g. using weather forecast.
2. Using buildings to facilitate the integration of large fractions of renewable energy.
3. Automatic energy labelling of buildings.
4. Providing advises on the best ways of improving the energy performance of a building.

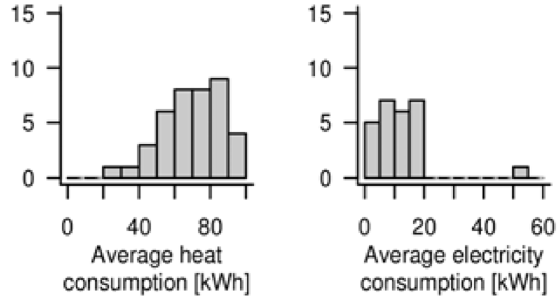
An essential role for ICT will be in facilitating the implementation of policy and in measuring its effectiveness. The Directive on the Energy Performance of Buildings introduces a general framework for a methodology to calculate the energy performance of buildings. The ICT sector can deliver tools that are vitally needed to collect, process, and manage the data, and present it in a standardized format. An example of the evaluation of collected data is given in the last part of the paper, where a method for estimation of thermal characteristics of single family houses based on measurements of energy consumption and climate is presented. The perspectives of the work presented here points toward an automatic and objective energy labelling of buildings (Nielsen et al., 2010). The methods can be used to supply users with valuable information about the energy performance of their house. The thermal characteristics can be presented via home-pages such as "Boligtjek" (www.goenergi.dk/boligtjek) by The Danish Energy Saving Trust (www.savingtrust.dk). Here the user can interactively gain information about the energy status of their house and give valuable information such as their typical indoor temperature, the use of night-time drop and wood burning stove. In addition to the interactive use the methods can also be used by e.g. district heating companies in order to screen for households with an unusual high consumption. In Denmark this is of interest to district heating companies since these are obliged to implement energy savings and from 2010 also energy savings in the network can be formally included in the total energy savings of a given district heating company.

Methods for improving energy efficiency using smart meter measurements

The next session is concerned with estimating thermal characteristics of single family houses based on measurements of energy consumption and climate. The main thermal characteristics describe how the building respond to: temperature differences between indoor and outdoor environment (UA-value), solar radiation (gA-value), and wind (wA-value). The effect of the wind can be characterized both in terms of the wind speed and the wind direction, implying that wA-values are estimated for different wind directions. Especially, the UA and wA-values are directly related to the insulation and air sealing of the building. The gA-values are related to the ability of the building to passively use solar heating. The estimated thermal characteristics have been analyzed with respect to background information regarding the households. This information is obtained via questionnaires and via the Danish Building Register (BBR). The significant effects are the ground area of the building, the year of construction, and the number of times per week a wood burning stove is used. This analysis is found in the Report (ENFOR, 2010a).

Further characterization of the building is the dynamic response to changes in climate variables. This is carried out by ENFOR (2010a), where the dynamic response is characterized by time constants of the response to temperature and solar radiation. Using such dynamical methods enables energy optimization by load management related to integration of renewable energy and peak-shaving. An example of applying dynamical methods as basis for energy optimization is for district heating where it can lead up to 20% savings of the heat loss in the distribution system Nielsen and Madsen (2002).

The data used in the present article consists of heat and electricity consumption data for the period from ultimo September 2008 to primo December 2009 from 56 households connected to the district heating system in Sønderborg, Denmark. Also climate data obtained at a local weather station within a few kilometres from the buildings. The energy consumption data is described in detail in the Report (ENFOR, 2010b). For 26 of the 56 households the electricity data is available, they are considered in this article. In the Report (ENFOR, 2010a) it is shown that the thermal characteristics of the building can often be well estimated based on measurements of the heat consumption alone. This is the case when the electricity consumption is not too large as it would be if for example electrical floor heating is used.



Daily sampling

The analysis in this article is carried out using daily power consumption values, i.e. using a sampling period of 1 day. With a unit resolution of 0.01 GJ this gives the daily consumption a unit resolution of 2.78 kWh/day, which is found to be sufficient for the analysis of daily values. Heat is estimated based on the difference in the accumulated consumption from midnight to midnight. The electricity consumption is treated in the same way. Distribution of daily averages is shown in Figure 1. Climate data are available in the period from 2008-10-06 to 2009-11-18 with a 10 minute sampling interval. The available variables are ambient air temperature T_a in ^{o}C, solar radiation R_0 in lux, wind speed w in m/s and wind direction θ in degrees. All climate data are down sampled to diurnal averages. The resulting distribution of the variables for a sampling period of 1 day is shown in Figure 2. The measurements of solar radiation is assumed to be dominated by direct sunlight and thus to be proportional with the effect of the direct sunlight.

The stationary heat transfer for a building is for the main part assumed to be comprised by three ways of heat transfer, namely through walls, windows, and by ventilation. Here heat transfer through the roof is assumed to be included as part of the model for the walls. By considering stationary models for heat transfer trough walls and windows and via ventilation a model with the following characteristics is derived:

- Responses on the temperature are collected into one term for which the coefficient is the UA-value.
- Responses on the solar radiation are collected into one term for which the coefficient is the gA-value.
- Responses on the product of the temperature and the wind speed are collected into one term for which the coefficient is the wA-value.

The model can only be used during the time period where the building is heated to maintain a constant indoor temperature, such that the heat transfer from the building can be measured based on the amount of energy supplied to the household. In the following it is shown how this period can be estimated.

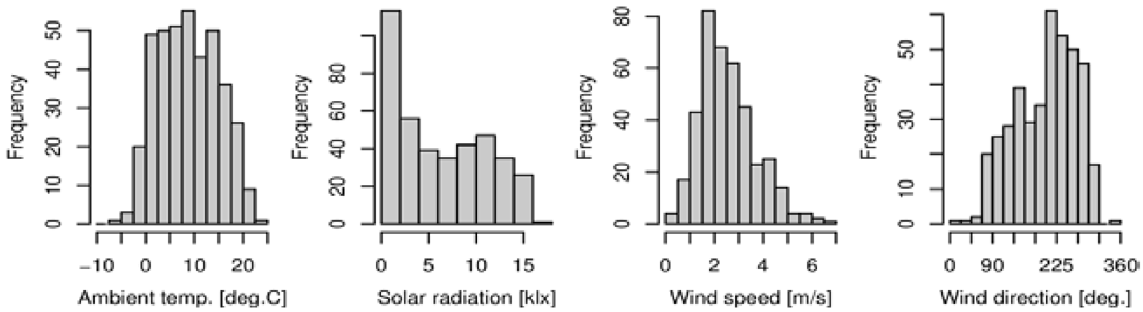


Figure 2: Daily averages of climate variables. The unit of solar radiation is kLux.

Analysis of daily values of power consumption

The estimation of UA and gA values and wind dependence is based on the assumptions outlined in the previous section. Unknown parameters in the model are UA, gA, v(θ). The function v(θ) is modelled either as a constant v(θ) = c_w or as piecewise constant for the major wind directions. There are only three days with an average wind direction from the northern quarter, and it is chosen to keep only three major wind segments, namely east (E) 0-135 deg., south (S) 135-225 deg., and west (W) 225-360 deg. The piecewise constant approximation to v(θ) is given as

$$v(\theta) = \sum_{j=E,S,W} I(\theta \in j) c_{wj}$$

where *I* is an indicator function equal to 1 when the argument is true and otherwise 0. The three coefficients c_{wj} gives wind dependence in the model and is interpreted as 'wA' values such that $wA_j = c_{wj}$.

Time varying estimates

Initial investigation of the energy consumption data is done by estimating the time variations of the coefficients in a linear and simplified version of the model outlined above. To reduce the number of parameters to be estimated the interaction between wind speed and air temperature is not included giving the model

$$Q_t = b_0 - UA \cdot T_{a,t} - gA \cdot R_{0,t} + b_1 \cdot w_t + e_t$$

where b_0 and b_1 are constants, $T_{a,t}$ is the ambient air temperature, $R_{0,t}$ is the solar radiation, and w_t is the wind speed. The coefficient b_1 cannot be interpreted in relation to the physical model, but it still gives an indication of wind speed dependence in the energy consumption.

The time variations are estimated using locally weighted estimation of the linear model. The method is described by Nielsen (1997) and gives local estimates in time of the model coefficients by only considering observations within a limited time window. This makes it possible to see if they are constant over time, e.g. to look for variations during the heating season and how they change during the summer period. Figure 3 shows these time varying estimates for two households. For the most of the households the UA, gA and b_1 values are relatively stable during the winter period which is also seen for these two households.

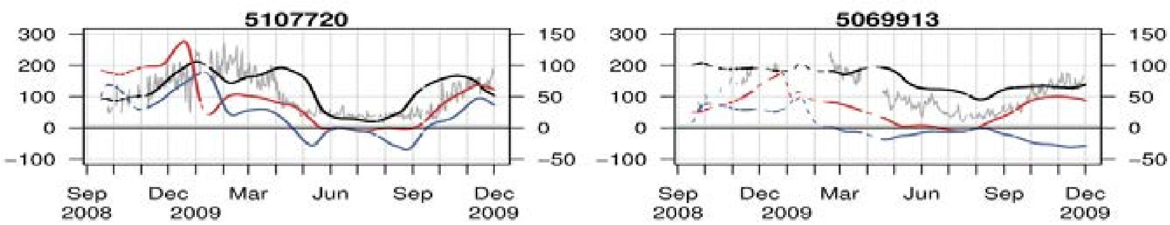


Figure 3: Time varying estimates of coefficients in Eq. (2). Black is UA [°C], red is gA [W/kLux] and blue is b_1 [W/m/s] all measured on the left side axis. The underlying gray curve is daily total energy consumption in kWh measured on the right side axis.

Parametric modelling of time-variations

Based on the estimates of time variations of the coefficients in the model in Eq. (2) it seems reasonable to assume that the coefficients can be modelled with a constant level for each of the two winter and one summer periods, giving three levels in total. Estimating when the changes in level occur will indicate the exact extent of the heating season for each individual building and this information can then be used to select the longest possible period of the actual heating season for further analysis. The model is estimated by means of partial linear estimation techniques and results are shown for the two selected households in Figure 4.

In previous work for estimation of UA-values alone based on daily averages of energy consumption (Nielsen, 2008) it has been found that there is significant dependence on the ambient temperature one day back for the heat consumption. This dynamic effect is also included here. In order to be able to get a good estimate of the effect of the solar radiation the heating season must comprise into the spring, where there is a significant contribution from the sun.

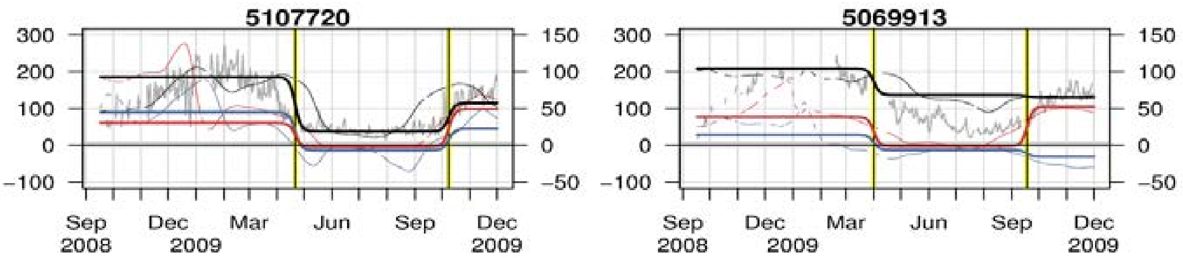


Figure 4: Thick lines are estimates of parametric models for time varying coefficients in Eq. (2). Black is UA [W/°C], red is gA [W/klux] and blue is b_1 [W/m/s] all measured on the left side axis. Thin lines are estimates based on local regression. Vertical black-yellow lines are estimated time point of change. The underlying gray curve is daily total energy consumption in kWh measured on the right side axis.

Results

Applying the model, which include sensitivity to wind direction gives the parameter estimates for the winter period shown in Figure 5. The estimated values are within realistic physical values. The estimates of the UA and gA^{max} values are all positive as they are expected to be except for one case of gA^{max}, which is considered an outlier. The estimates of the wA_*^{max} values are mostly positive, although there are some negative estimates indicating a reduced UA value for these wind directions. However, overall the estimates of the wA_*^{max} values gives a picture of the wind dependence for each house, and it is seen that some are clearly more wind sensitive than others. A thorough analysis of the results is found in the Report (ENFOR, 2010a).

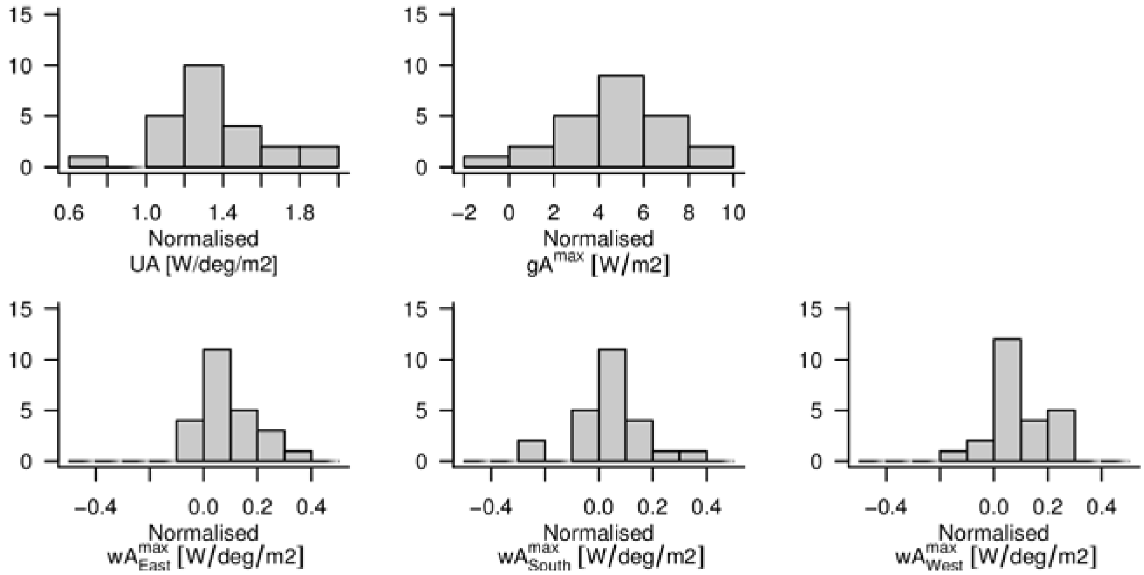


Figure 5: Histograms of estimates of estimates normalized by floor area.

Discussion on the estimation of energy performance of single family houses

A fundamental assumption of the present method is that measurements on a short time scale are available. During the recent years such measurements has started to appear, both for electricity, district heating, and natural gas consumption. Obviously, measurements performed with a high frequency imply higher demands for bandwidth and data storage. Maybe less obviously high frequency measurements also require better resolution of the basic measurement equipment. The resolution of the measuring equipment compared with the time resolution can have an important effect on information embedded in the data. In the present study a unit resolution of 2.78 kWh/day has proved to be sufficient for estimation of the energy performance of single family houses. For energy optimization by load-shifting using dynamical methods a higher time resolution is needed. Finally it is noted that additional information about the buildings can be collected via platforms like "Boligtjek" (www.goenergi.dk/boligtjek), which allows users anonymously to share information such that the analysis is performed based on all available data.

Conclusion

The presented method for estimation of the thermal characteristics of single family houses gives an objective and automatic description of the energy performance of individual buildings, based on measurements of energy consumption and climate. It is possible to determine how well a building is insulated, combined with its wind sensitivity for the prevailing wind directions and its ability to passively use solar heating. This implies estimation of the coefficients characterizing the response of the building to differences in temperature (UA-value), solar radiation (gA-value), and wind (wA-value). Such methods based on measurements from smart meters, can enable ICT-facilitated improvements of building energy efficiency by means such as: providing objective methodologies to calculate the energy performance of buildings for implementation of policy and in measuring its effectiveness, providing advises on the best ways of improving the energy performance of a building, and enhancing the energy awareness of users by interactive web-pages.

References

[1] Bloem, H., Atanasiu, B., 2009. Dynamic analysis methodologies applied to energy management in residential buildings. In: EEDAL'09 Conference 16-18 June, Berlin, Germany.

[2] Costa, A., Crespo, A., Navarro, J., Lizcano, G., Madsen, H., Feitosa, E., 2008. A review on the young history of the wind power short-term prediction. Renewable and Sustainable Energy Reviews 12 (6), 1725 – 1744.

[3] ENFOR, 2010a. Analysis of energy consumption in single family houses. Tech. rep. URL http://www.enfor.dk/pub/03EKS0009A002-A.pdf

[4] ENFOR, 2010b. Detailed measurements of heat and electricity consumption in sønderborg households during the herating season 08/09. Tech. rep. URL http://www.enfor.dk/pub/03EKS0009A002-A.pdf

[5] EU, 2010. EU Directive 2010/31/EU on Energy Performance for Buildings from 19 May 2010.

[6] ICT-REEB, July 2009. ICT for a low carbon society - Smart Buildings. URL http://ec.europa.eu/ictforsgISBN978-92-79-12977-3

[7] Nielsen, H. A., 1997. LFLM version 1.0, an S-PLUS / R library for locally weighted fitting of linear models. Tech. Rep. 22, Department of Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark.

[8] Nielsen, H. A., 2008. Estimation of UA-values for single-family houses. Tech. rep., ENFOR.

[9] Nielsen, H. A., Mortensen, S. B., Bacher, P., Madsen, H., 2010. Analysis of energy consumption in single family houses. In: DYNASTEE, 11-12 October 2010, Brussels.

[10] Nielsen, H. A., Nielsen, T., Madsen, H., 2002. On on-line systems for short-term forecasting for energy systems. In: Proceedings OR 2002 Conference, p. 265-271, Klagenfurt, Austria, Springer, 2002.

[11] Nielsen, T. S., Madsen, H., 2002. Control of supply temperature in district heating systems. In: Proceedings of the 8th International Symposium on District heating and Cooling. Trondheim, Norway.

[12] COM(2011) 202 final Smart Grids: 'From Innovation to Deployment' (April 2011).

[13] 2006/32/EC Directive on Energy end-use Efficiency and Energy Services.

[14] 2009/28/EC on the promotion of the use of energy from renewable sources

[15] RE&EV 2010. Proceedings of the Workshop on "Electric Cars and integration of Renewable Energy at the 2020 horizon", http://re.jrc.ec.europa.eu/energyefficiency/events.htm . Lyngby, 10 - 12 March 2010.

Energy Savings with Air-to-Air Heat Pumps – True or False? Findings and Policy Implications from a Danish Study

Kirsten Gram-Hanssen and Toke Haunstrup Christensen

Danish Building Research Institute, Aalborg University

Poul Erik Petersen and Troels Fjordbak Larsen,

IT Energy ApS

Erik Gudbjerg and Lisbet Stryhn Rasmussen

Lokalenergi A/S

Preben Munter,

SEAS-NVE

Abstract

Air-to-air heat pumps are increasingly promoted as a means for energy savings – but do they "keep their promise?"

If installed, maintained, and used properly, air-to-air heat pumps can provide high efficiency heating of dwellings as compared to direct electric heating. The latest Danish energy agreement therefore includes heat pumps as one of the measures. However, energy savings not only depend on efficient appliances, but also on installation, maintenance, and user practices. Examples of user practices which can counteract the energy savings include changes in the residents' thermal comfort practices such as higher indoor temperatures and air conditioning in the summer. Maintenance and installation defects include restricted airflow, leaky ducts, long line sets etc., but can also include wrong default settings or incorrect operation due to a difficult user-interface. Thus, reasons for inefficiency might be technical as well as practice-related.

This paper presents results from a survey of user practices combined with information from utilities on electricity consumption among households with air-to-air heat pumps. The study explores to what extent households realise actual energy savings when installing heat pumps. Results indicate that in permanently occupied dwellings there are significant energy savings even though they are less important as compared to what should be expected from a technical view. This can be explained by some households raising their comfort norms, including some the use of the heat pump for air conditioning. In summerhouses, however, results indicate that energy savings are only realised for some households whereas others realize increased electricity consumption following from new habits such as heating the summerhouse all year, even it is primarily used in the summertime.

Introduction

According to technical specification of heat pumps they typically convey a reduction of two-thirds of the electricity consumption as compared to direct electric heating. The question, however, is to what extent these reductions are actually realised on the field. From research in energy efficiency and consumer behaviour it is well documented that when efficient technologies are put into use the potential savings are not necessarily met. The so-called "rebound effect" is an economically based interpretation of how (some of) the money saved on efficiency will be used on increases in more consumption, e.g. higher comfort temperatures. A comprehensive review study of the rebound effect within energy efficiency in the household sector concludes that approximately 20% of the potential savings for heating is transformed into higher consumption rather than savings [1]. Also studies with a socio-technical approach have studied how development of new technologies goes hand in hand with development of new norms and expectations of what is convenient and comfortable and thus leads towards still higher expectations [2]. Though there are not published studies focusing explicitly on the use of heat pumps within these approaches, there are reasons to believe that the same tendencies may be found when installing heat pumps. For instance an unpublished spot test among 80 heat pump customers showed only on average 11% reduction in electricity consumption after installation of heat pumps.

The purpose of the present study is thus to explore to what extent the potential energy savings from the use of heat pumps are reached when used in real life or if changes in comfort practices, wrong use and installation or maintenance of the technology or other factors are responsible for reduced savings. When answering these questions it is relevant to distinguish between use of heat pumps in permanently occupied dwellings and in summerhouses as it must be anticipated that the use in these two different settings are qualitatively different and furthermore they have also been marketed in different ways.

There are about 215,000 summerhouses in Denmark [3] and most of these were built during the welfare boom in the 1960s and 70s, often in coastal areas or close to lakes and forests. Danish summerhouses, which typically have a floor space of 60-70 m^2, are mainly used by their owners in holidays and weekends during the summer and less often in the winter. About 15% of the summerhouses are used (legally or illegally) as permanently occupied dwellings, mainly by old-age pensioners [4] [5]. The majority of the summerhouses (app. 84%) have direct electric heating installed while only about one out of ten has an air-to-air heat pump [6].

The majority of the permanently occupied dwellings in Denmark have central heating, based on district heating, gas or oil, Though, app. 119,000 dwellings, or 8% of the total Danish dwelling stock (only single-detached, semi-detached, terraced and farm houses included here), are heated by direct electric heating, while only 7,700 have a heat pump as their primary heating form [7]. The Danish Energy Agency estimates that the number of installed air-to-air heat pumps is about 75,000 [8]. Many of these probably supplement other forms of heat supply (e.g. direct electric heating). Thus, the total potential for further substituting electric heating with air-to-air heat pumps is considerable, which is also why Danish energy authorities at the moment subsidy installation of heat pumps. This makes it further relevant to research to what extent heat pumps actually delivers energy savings.

The following of this article first explain the methods of the study and then go into details on the analysis of first the permanently occupied dwellings and secondly the summer houses, and then in the discussion and conclusions results are considered in an energy policy perspective.

Methods

Data presented in this paper are based on a survey from 2010 among house owners in two Danish regions who installed air-to-air heat-pumps. The survey population of 2793 households was obtained from two Danish energy companies with sales information on heat-pump ownership including summerhouses and permanently occupied dwellings with heat pumps. A sample of 681 house owners or 24.4% within the population completed the questionnaires. The questions towards summerhouses differed slightly from those to all-year houses. In the questionnaire people are asked to indicate the type and fabrication of heat-pump, and based on this, only questionnaires from households which for certain have an air-to air heat pump are kept in the analysis. This includes 481 houses, whereof 76 are summerhouses. Analysis of these questionnaires is provided in the following section, including questions on heat pump usage and comfort practices.

The questionnaires are also combined with energy consumption data, as delivered from the energy companies, from the years 1990 to 2009 to be able to detect any changes in energy consumption in the households following the installation of the heat pump. Some questionnaires are removed from this part of the survey if the year of installation of the heat pump is unknown, or if the installation year is too recent or too old in order to have at least one whole year of energy consumption both before and after installation. This results in a dataset of 185 questionnaires, whereof 47 are for summerhouses. Among summerhouses a follow-up survey was conducted with some additional questions. Survey data thus include different sets of data, one consisting of 481 households, where electricity consumption is not included, and one consisting of 185 households where survey results are combined with energy consumption information. The survey dataset are summarized in table 1.

Table 1. Number of households in survey dataset

	Total	Permanently occupied dwellings	Summer houses	Follow-up on summer houses
Questionnaire survey	481	405	76	35
Survey including electricity consumption	185	138	42	16

SPSS statistical analysis has been used on the four different datasets [10].[1] For the questionnaire data set descriptive analysis have been carried through and for the survey including electricity consumption descriptive analysis as well as regression models have been used. The follow-up survey is only used for commenting on other analysis and not analysed quantitatively due to the limited number of respondents.

The study also includes qualitative interviews with twelve households selected from the survey and visual inspections of the operation and maintenance-standard of these households' heat pumps. The technical inspections focused on visible conditions that might reduce the efficiency of the heat pump, including the condition of the evaporator/condenser (physical damages or dirt obstructing air flow) and risks of "thermal short-circuit" due to the placing of the evaporator/condenser. Results from the interviews and inspections are further described in Christensen et al [9].

The last part of the project looks into a future potential cooling demand from Danish households including scenario estimates on the correspondingly energy demand. This part has not yet been published.

Analyses of the results are divided into two sub samples, where the first focuses on results from permanently occupied dwellings and the second focuses on results from summerhouses. Both of these parts will be distinguished between the two datasets of questionnaires by analysis without electricity consumption and analysis explicitly related to questions of changes in electricity consumption.

Analysis of permanently occupied dwellings

Analysis of survey dataset on permanently occupied dwelling

This section provides descriptions of the households answering the survey. As shown in table 2, on the age distribution, those answering the survey are older than the population in general in these regions. This also influences the rate of employment, where 44% of those participating in the survey are retired persons receiving pension where the same only apply to 26% of the population on a national level (not shown here in table). This can also be retrieved in the income distribution among those answering the survey. In table 3 it is seen that those answering the survey to a higher extend are in the lower income groups as compared to all house owners in the region.

The problem with these descriptions of the survey respondents in comparison with the general population is that we do not know to what extent they show, that it is a special segment of the population that are having heat pumps or if there is a special segment of those having heat pumps

[1] Statistical Package for the Social Sciences (SPSS) software was first released in 1968 after being developed by Norman H. Nie and C. Hadlai Hull. SPSS is used for statistical analysis in social science. The original SPSS manual was written by Nie, Bent & Hull in 1970.

that has answered the questionnaire. When interpreting results it is of importance to notice that the respondents in general are quite old and not among the wealthiest of the house owners.

Table 2. Age distribution in survey and in general in the regions of the survey

	Survey	Population in regions
0-40 years	5,4%	32,1%
40-60 years	45,9%	38,0%
60- years	48,6%	29,0%

Table 3. Income distribution in survey and among house owners in the regions of the survey

Income per year, DKK	Income per year, euro	Survey	House owners in the regions
Less than 200.000	Less than 26.000	10,2%	9,3%
200-399.000	26-53.000	35,1%	24,5%
400-599.000	53-80.000	24,9%	22,5%
More than 600.000	More than 80.000	29,9%	43,7%

Table 4. Reasons to purchase the heat pump

	Number	Per cent
To save money on heat consumption	290	72%
To save energy	257	63%
To improve comfort	152	38%
Contributing to reduced pollution	92	23%
Heating system needed renewing	14	3%
Not applicable, Heat pump installed before we moved in	39	10%
Others	27	7%

Respondents have been asked why they purchased the heat pump. As seen in table 4, the majority has done this to save money and energy, and to a lower degree to improve their comfort. More than two third of the respondents indicate that they are very satisfied with their heat pump, and only one percent that they are very unsatisfied with it (not shown in table).

Use of the heat pump and changing norms of comfort in all-year houses

The majority (86%) of the respondents used electricity for heating before they bought the heat pump and many of them (approximately 60%) use the heat pump as primary heat source now, though only 11% indicate that the heat pump is their only source for heating purpose. Approximately 50% of the households combine heat pumps with a wood burning stove and the majority use electric heating, with either heat pump or electricity as the primary source. 164 respondents had a wood burning stove before they got the heat pump and among those there are 39% who indicate that they use less wood after they got the heat pump, 39% indicate that it has not influenced their wood burning habits, 31% do not know and only 3% indicate that they use more wood after they got the heat pump. It seems thus that heat pumps in some households have substituted wood rather than electricity for heating purpose.

Table 5. Changing heating practices related to heating season after purchase of heat pump

	Number of households	per cent
No change	206	50,9%
Heat is turned on for a shorter period of the year than previous	93	23,0%
Heat is turned on for a longer period of the year than previous	69	17,0%
Not applicable, Heat pump installed before we moved in	37	9,1%
Total	405	100%

Table 6. Changing heating practices related to temperature after purchase of heat pump

	Number of households	Per cent
Same temperature as previously	223	55,1%
Temperatures are generally kept higher than previously	123	30,4%
Temperatures are generally kept lower than previously	19	4,7%
Not applicable, Heat pump installed before we moved in	40	9,9%
Total	405	100%

The question if people change their heating practices and norms of comfort after purchase of the heat pump is a main research question in this paper. In table 5 it is seen that 50% of the households themselves do not believe that they have changed habits in relation to how much of the year they heat their house, and more people (23%) believe they heat for a shorter period after they have got the heat pump, than the percentage (17%) who believe they now heat for a longer period than before they purchased the heat pump. There is thus no reason to believe that the heat pump in general entail a longer heating season. If we look at table 6, there is however indication that approximately app.one third of the households established a higher temperature setting after they purchased the heat pump compared to previously, and only 5% think they keep a lower temperature.

Another way of raising the comfort is to enlarge the heated area, e.g. start to heat rooms which were not previously heated. 13% of the respondents indicate that more rooms are heated after the purchase of the heat pump, and these rooms are typically 10-30 m^2.

A last and major issue related to the question of changing norms of comfort is the question if people use their heat pump for air conditioning. First question is if people know about the possibility that their heat pump can be used for air conditioning. 76% of the respondents indicate that their heat pump can be used for air conditioning, 22% state that it cannot (which is probably wrong) and only 3 % say that they do not know. Among the 306 respondents who know that their heat pump can be used for air conditioning, 21% of households have actually used it and those 64 households have furthermore estimated how much they use it as an air-conditioner. In table 7 it is seen that one third use it only a few days and that 17% of those who knew their heat pump could be used for air conditioning used it more than 15 days during a normal summer.

Table 7. Number of days the heat pump have been used for air conditioning

Number of days	Number of households	Per cent
1-4 days	24	38%
5-9 days	17	27%
10-14 days	12	19%
15 days or more	11	17%
Total	64	100%

Summarizing the results based on the survey among permanently occupied dwellings, there isare some evidence for changes in habits relating to heating and indoor climate. First it seems that those who combined wood burning stove with electricity for heating before they installed the heat pump, to some extent reduced their use of the wood burning stove. This means that the reduction in electricity consumption will not be as big as otherwise anticipated. Whether substituting wood burning with the use of heat pump should be considered environmentally sound is open for debate. There does not seem to be any evidence that people in general will extend the heating season because they acquire a heat pump, maybe even the contrary, though there is some evidence that some households raise their indoor temperature following the acquisition as well as there are some households who start to heat more indoor space. Only a minority of the households use the heat pump for air conditioning, though for some of the households it is more than two weeks a year and thus must influence their electricity consumption. With these summaries in mind, we will now continue to look at the data analysis where survey results are combined with electricity consumption, to see if we can detect any correlation between reduction in electricity consumption and purchase of heat pump.

Analysis including electricity consumption, permanently occupied dwellings

When analysing to what extent purchase of heat pump is followed by a reduction in electricity consumption, several other variables and factors have to be included in the comparison. First is that the outdoor temperatures varies from one heating season to another, which imply that data for electricity consumption for heating purpose have to be corrected according to degree days. As electricity is used for other purposes than heating we have to estimate the share of electricity in each household that is used for heating purpose and only make degree day correction for this. Knowledge of the number of people in the households and the size of the building has been used to estimate the share of electricity which is not used for heating purpose, and the rest are thus degree day corrected. It is this degree day corrected electricity consumption that is used in all the following analyses.

In figure 1 each household's degree day corrected electricity consumption before and after installation of the heat pump is compared. It is seen that the slope is below one, indicating that for the majority of the households' electricity consumption after installation of heat pump is lower than before, as would be assumed. However, especially households with lower levels of electricity consumption before installation of heat pump do not necessarily realise a lower level of consumption after installation. As described in the previous paragraph there might be different explanations that a household does not display reduced electricity consumption when installing a heat pump, which will be further analyzed.

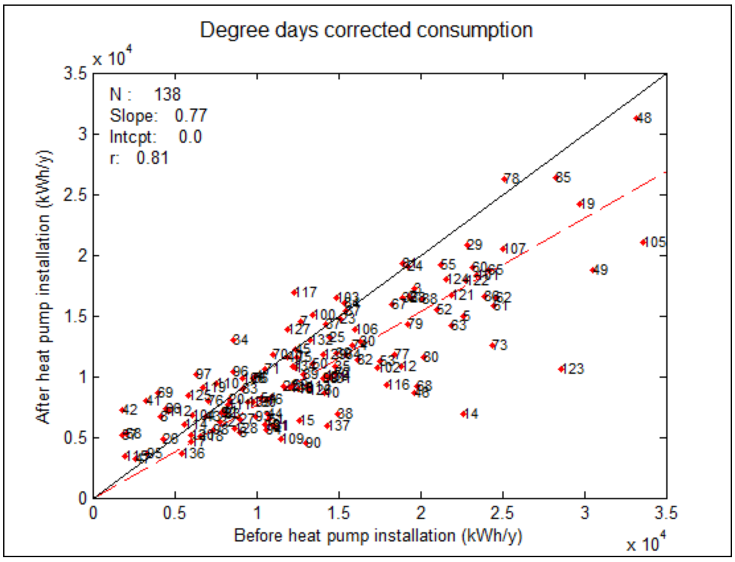
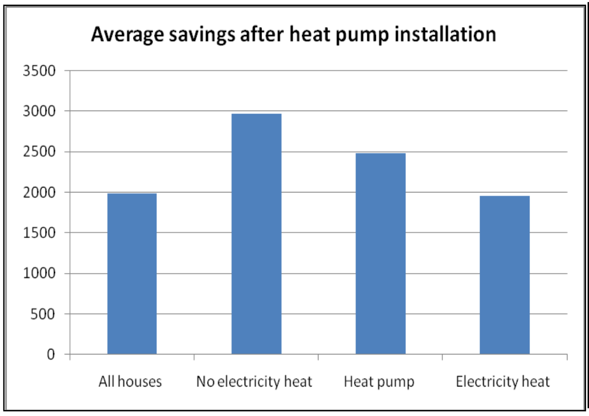


Figure 1. Comparing yearly household electricity consumption before and after heat pump was installed. Electricity consumption for heating is degree day corrected.

A major explanatory variable is expected to be the question of what the primary heating source was before and after installation of the heat pump. In figure 2 the average savings in all households are shown together with combinations of what the primary heating source was before and after installation of heat pump. Besides a degree day correction, these average saving values are also corrected for a yearly decrease in consumption of 5%. These 5% reduction are calculated on the basis of comparing one year with the following for the years where the surveyed households did not install the heat pump.



1. All houses: All houses degree day corrected and corrected for a yearly 5% general decrease (N=138)
2. No electricity heat: Houses using direct electricity heating before heat pump installation and no direct electricity heating after (N=16);
3. Heat pump: Houses using direct electricity heating before heat pump installation and using heat pump as primary heating source after (N=70);
4. Electricity heat: Houses using direct electricity heating before heat pump installation and after still using direct electricity as primary heating source. (N=32)

Figure 2. Average savings in annual household electricity consumption (kWh) before and after heat pump was installed, for different combinations of heat supply before and after installation of heat pump. For all four cases the savings are significantly different from zero.

In all four cases in figure 2 a paired samples test shows that the savings is significantly different from zero (not shown here), though there are big variations for the savings especially among the third case, which is also where we see the biggest average savings and where we have a low number of households. The biggest average savings (and the biggest variation) are thus not surprisingly seen in households where they used direct electric heating before they installed the heat pump, and where they do not use any direct electric heating after the heating pump is installed.

As there are numerous variables which might influence change in electricity consumption other than the installation of the heat pump, the following will show results of regression analysis with all available variables known from the survey. These variables include change in primary heat supply, in household's members, in numbers of rooms, in heating period, in heating temperature, in cooling days, in appliances, in isolation of the house, in installation of wood burning stove or in saved firewood. Furthermore there are some descriptive variables on the household members as number of children and adults, and household income and descriptions of the house as size and age of house and the heated area. The regression analysis can be described by the equation:

$$Xafter_i = a + b \cdot Xbefore_i + \sum_{j=1}^{N} c_j \cdot X\mathrm{cov}_{i,j} + \varepsilon_i$$

Where *Xafter* is the electricity consumption after heat pump installation, *Xbefore* is the consumption before, and Xcov are the different other variables. Results of the full regression analysis are shown in appendix. The *b* coefficient to *Xbefore* is a measure for the heat pump effect and possible other effects not included in *Xcov*. The only variables from the *Xcov* matrix that are found significant are if people have bought an extra TV, and the income level of the household.

Using forward selection and stepwise regression noisy variables are removed from the regression thus revealing an extra variable to be significant. This is the variable for change in heating period. In the appendix it is seen that this was almost significant in the full regression analysis. It is thus interesting that what seem to explain change in electricity consumption other than the installation of the heat pump are variables related to general wealth, consumer behavior and to change in heating practices.

The combination of the four variables is the best explainable combination we can get by these methods on these data. However, it is possible to collect another combination of variables (by some other method) that may explain Xafter equally or almost equally well. When such a new variable combination is collected no other variable can contribute to make a significantly better explanation. This does not mean that the excluded variables do not have any influence for some of the specific cases. For instance, we know that cooling contributes to the energy consumption. Why is this not significant in the model?

There are several reasons for the variable exclusion of the model. First of all, the amount of data cases is crucial. If we have infinite data we may also detect very small effects from other variables.

One reason is that correlations among variables tend to decrease when data cases increase. Thus, the variables become independent. However, some non-known events may also interfere. This could be changes in behaviour such as winter holidays and other things that will contribute to the noise in the model because we do not have the information. Such 'noise' may hide or counteract effects for some other variables that thereby become insignificant. Furthermore, the accuracy of the variables may be important. For instance, a variable as temperature increase is better in degrees with high accuracy than just categories as higher, normal, and lower. Thus, the insignificant variables may still be interesting to study. Their quantitative effect may be blurred in the study, but the effect has not disappeared in the real world.

However, the main effect arising from Xbefore is strongly significant and the corresponding coefficient is estimated to 0.6 as seen in the appendix. This means that the effect of the heat pump together with the 5% general yearly decrease gives a reduction of 40% of the electricity consumption. Thus the heat pump alone gives a 35% reduction in electricity consumption. In figure 3 results from the full regression analysis is shown and it is seen that the prediction of the electricity consumption is much higher (r=0.92) as compared to figure 1 where we had r=0,81.

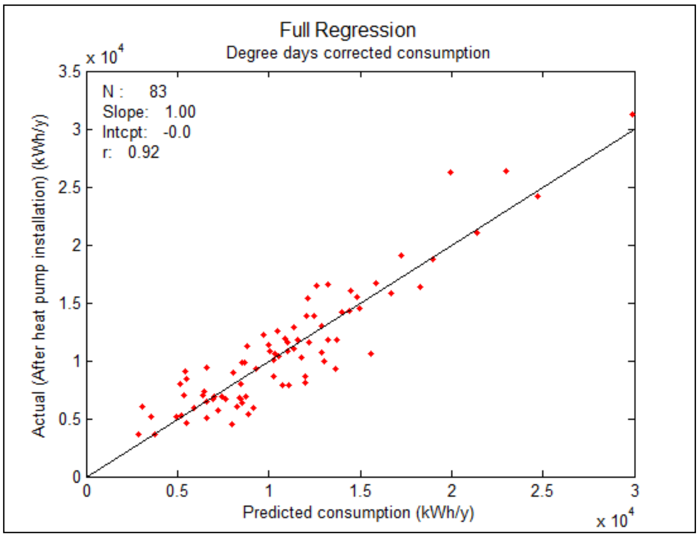


Figure 3. Comparing yearly household electricity consumption after installation of heat pump with predicted electricity consumption based on full regression analysis.

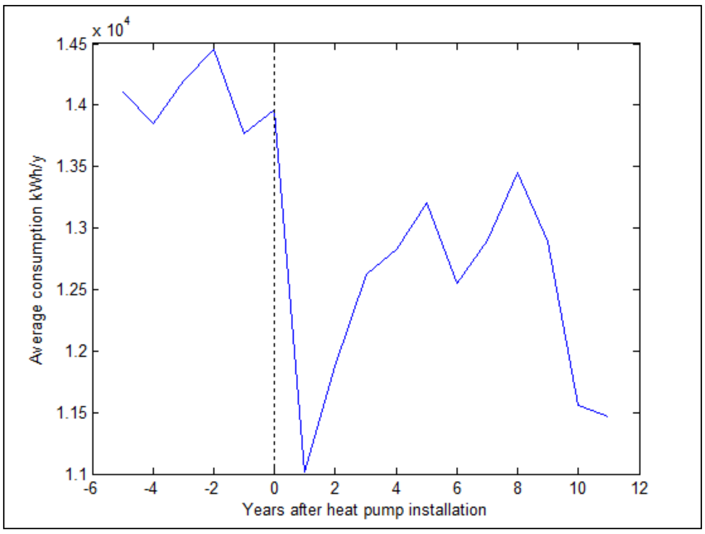
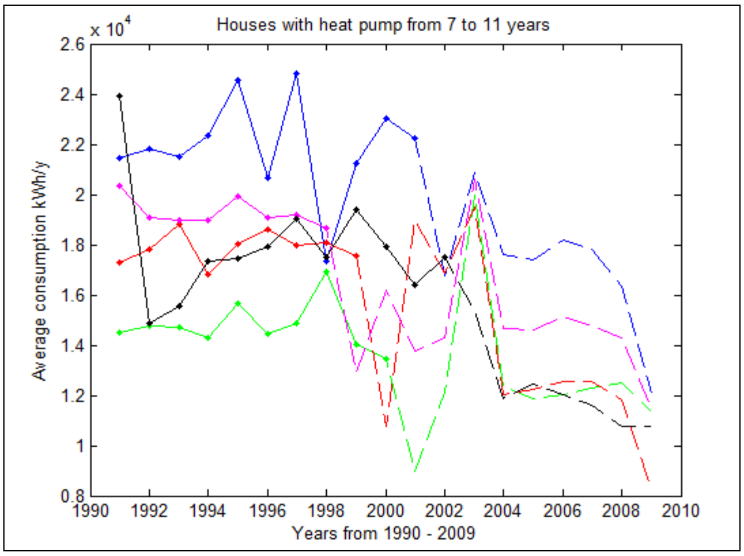


Figure 4. Following the average household electricity consumption year by year before and after installation of heat pump

In the previous analysis electricity before and after installation has been summarized for several years from 1990 to 2009 depending on when in the period the heat pump was purchased. Another approach to study the impact on electricity consumption after installing a heat pump is to analyze how electricity consumption develops in the year after the purchase. Figure 4 show how the average yearly consumption develops year by year after installation. Please notice that there are more observations covering the first years after installation than the last years. We see that electricity consumption are rather low the first year after installation, and then the following years it rises, falls at bit, and rises again, and then after 9-10 years it falls again. This is potentially interesting as it might indicate that people save more the first year after installation, and then when they have got used to the lower electricity consumption, they start to use more.

Figure 4, however, includes many different possibilities of misinterpretation, as it summarizes and shows average consumption. In figure 5 the x-axis is the actual calendar year, thus allowing us to follow if there are some years that all people behave different. Here, it is seen that year 2003 is a year where all lines (except the black) has a peak. When looking for characteristic of this year it should be remembered that data are already degree day corrected, so extreme winters are taken into account. Though the peak might be explained by the fact that it was actually an extraordinary hot summer, where many people might have used the heat pump for air conditioning. If we discard the 2003 point in figure 5, the tendency seems to be a first year of energy saving after installation, followed by a small increase, then a stable period and finally a new reduction of consumption.



Year of installation of heat pump (HP):

Black = HP in 2002 (n=10)

Blue = HP in 2001 (n=3)

Green = HP in 2000 (n=7)

Red = HP in 1999 (n= 9)

Magenta = HP in 1998 (n= 11)

Figure 5. Following the average household electricity consumption after installation of heat pump, distinguishing between the years of installation of heat pump

Analysis of summerhouses

Analysis of summerhouse survey dataset

The survey included 76 summerhouses with an air-to-air heat pump installed. The respondents of the survey on summerhouses are quite old and also older than the average summerhouse owner. 91% of the respondents are more than 50 years, the national corresponding figure for summer house owners more than 50 years is 78% [4] and in the survey more than 75% of the respondents are older than 60 years. This also means that the majority of the respondents are pensioners.

Table 8. Reasons to purchase the heat pump in summerhouse

	Number	Per cent
To save energy	46	61%
To improve comfort	40	53%
To keep the summerhouse non-freezing in wintertime	39	51%
To save money on heat consumption	38	50%
Contributing to reduced pollution	16	21%

Heating system needed renewing	0	0%
Not applicable, Heat pump installed before we moved in	2	3%
Others	6	8%

In table 8 are listed the answers to the question of why people have purchased their heat pump for the summerhouse. A majority of 61% indicate to save energy as a reason, and the second and third most often indicated options are to increase comfort and to be able to keep the summerhouse non-freezing in wintertime. Half of the respondents indicate saving money on heat consumption, and if we compare with table 4 we see that 72% of owners in permanently occupied dwellings indicate that the reason the purchase a heat pump was to save money on energy. It thus seams that there are slightly different reasons involved when purchasing a heat pump for the summer house and for the permanently occupied dwelling, which is also displayed in the answers respondents have filed in under “Others”, which includes: “Having a nice temperature when we arrive at the summerhouse”; “Better use of the summerhouse in winter time”; “Higher temperatures in wintertime with lower consumption”.

In more than two third (72%) of the summerhouses the heat pump is the primary heat supply, and more than half of the respondents indicate that they used electric heating as their primary heat supply before installation of the heat pump. Furthermore 80% indicate that they also use firewood for heating, and among those who had firewood burning stove both before and after installation of the heat pump half of them (47%) indicate that they use less firewood after purchase of the heat pump.

Use of the heat pump in summerhouses and change in norms of comfort

People were asked about changes in their heating practices and norms of comfort following their purchase of the heat pump. Table 9 and 10 summarise the answers. Here it is seen that more than half of the respondents indicate that they heat for a longer period and keep a higher temperature after purchase of the heat pump.

Table 9. Changing heating practices related to heating season after purchase of heat pump

	Number	**Per cent**
No change	25	33%
Heat is turned on for a shorter period of the year than previous	5	7%
Heat is turned on for a longer period of the year than previous	42	55%
Not applicable, Heat pump installed before we moved in	4	5%
Total	76	100%

Table 10. Changing heating practices related to temperature after purchase of heat pump

	Number	**Per cent**
Same temperature as previously	32	42%
Temperatures are generally kept higher than previously	40	53%
Temperatures are generally kept lower than previously	1	1%
Not applicable, Heat pump installed before we moved in	3	4%
Total	76	100%

In the follow-up survey it is confirmed that 23 out of 27 people heat their summerhouse to more than 10 deg. C, after purchasing the heat pump, whereas some closed the house completely before installation of the heat pump and most of the others kept a lower temperature, just securing non-freezing. It is interesting to notice that for the majority of the types of heat pump, which people indicate they have installed, it is not technically possible to have a set-point of the temperature lower than 16 deg. C, meaning that a majority of the summerhouses now are heated to 16 deg C, through all wintertime.

Table 11. Number of days the heat pump has been used for air conditioning in summerhouses

Number of days	Number	Per cent
1-4 days	10	63%
5-9 days	4	25%
10-14 days	2	13%
Total	16	100%

The respondents have been asked if they were aware that their heat pump could also be used for air conditioning. Only about half of the respondents are aware of this, and among these, less than half (41%) has actually used it for air conditioning. In table 11, it is seen that only 6 households indicate that they have used the heat pump for air-conditioning more than 5 days a year. In the follow-up questionnaire only 4 out of 35 respondents indicate that the fact that the heat pump can be used for air-conditioning was part of the reason that they bought it. The survey thus indicates that air conditioning is not a major explanation for missing reduction in electricity consumption with heat pump installation.

Summarising about heat pumps in summerhouses it must first be noticed that the statistical basis of 76 respondents is quite small. However, survey results indicate that the reasons to buy a heat pump differ slightly from permanently occupied dwellings to summer houses. In summerhouses the owners to a higher degree indicate higher comfort as a reason to purchase the heat pump and this is confirmed by the responses to questions on changes in heating practices. In summerhouses more than half of the respondents keep a higher temperature and heat for a longer period after purchase of the heat pump as compared to previously.

Analysis of dataset with electricity consumption, summerhouses

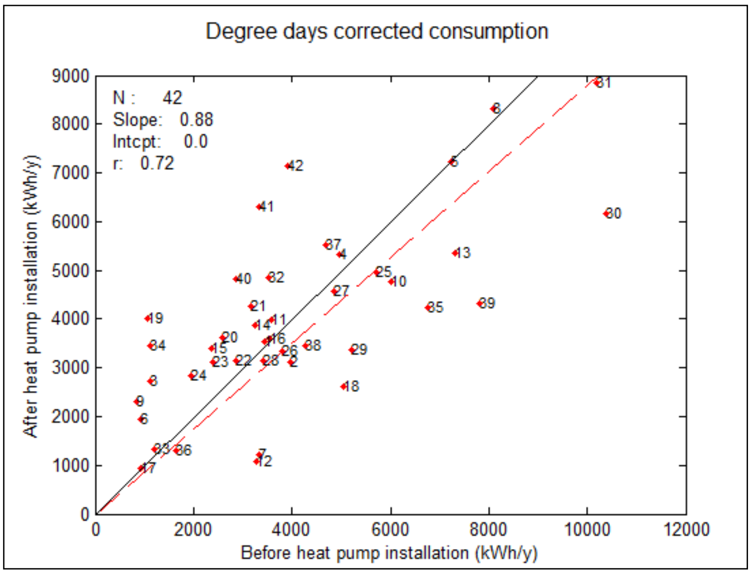


Figure 6. Comparing yearly household electricity consumption before and after heat pump was installed in summerhouse. Electricity consumption for heating is degree day corrected.

When combining survey results on summerhouses with knowledge on electricity consumption we have 42 cases. This number is a bit small for proper statistical analysis including all available variables, and the number of the supplementary variables is too high relative to the cases. Figure 6 show a comparison of electricity before and after purchase of the heat pump for these 42 summerhouses. It is seen that the slope of the line is below 1 thus showing an over-all reduction in electricity consumption after installing the heat pump. Although, we detect a slope by the regression a pair-wise test shows that the mean difference is not significant different from zero. The slope thus arises from high consumption cases having high leverage. Among summerhouses with low electricity consumption there seems to be a tendency that they have an increase in electricity consumption after purchase of the heat pump. Regression analysis including supplementary variables confirms that it is a significant relation that summerhouses with low levels of electricity consumption experience an increase in electricity consumption, an increase which cannot be explained by any of the supplementary variables. It is reasonable to assume that some summerhouses with electricity consumption below 3000 kWh, only to a limited degree did heat their house with electricity before installing the heating pump, and that the increase in electricity partly is a result of an increase in heating season and temperature in wintertime.

Further calculations on summerhouses

As there are a limited number of cases in the data set on summerhouses which also include information of electricity consumption we have carried out theoretical calculations on a model summerhouse to answer the question of how much more electricity it takes to maintain 15 deg. C rather than 5 deg. C. throughout a winter. In order to estimate the heating load at different indoor temperatures for typical Danish summer houses, a number of assumption are established. The summer house model has the following primary parameters: Floor area: 100 m^2; U-value for walls/roof/floor: 0.15 W/(m^2*K); U-value for windows: 1.5 W/(m^2*K); Windows area: 20 m^2; No pool or sauna is installed; No internal heat sources from appliances are assumed at reduced indoor temperatures when the summer house is unoccupied; Solar insulation during windows is taken into account. The data chosen should correspond to a typical 5-10 years old Danish summer house.

As a tool for the calculation of the yearly heating loads the Be05 program has been used [please include reference for Be05 program]. The normalized heating load (kWh/m^2) – using the Design Reference Year for Denmark – is presented in the graph below at different average indoor temperatures. The average outdoor temperature during the heating period in Denmark is some 4 C.

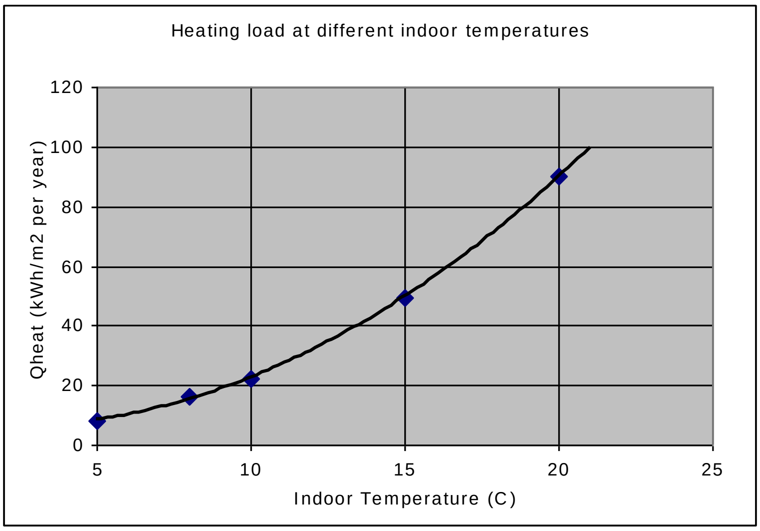


Figure 7. Calculation of heat demand in a model summerhouse dependent on indoor temperature

A summerhouse of 100 m^2 that is heated to 15 deg. C throughout the winter thus require 5000 kWh to be heated by direct electric heating or 1333 kWh/year to be heated by a heat pump (seasonal factor 3.75). A summerhouse that is heated by direct heating to 5 deg C. throughout the winter requires 800 kwh/year.

Discussion

When discussing results presented in this paper, there are some methodological challenges to bear in mind. First challenge is to get in contact with households having installed a heat pump. In this project we benefitted from customer lists from two local energy companies, which potentially could provide address and yearly energy consumption for 2793 households. In the end this resulted in 681 answered surveys and for 185 of them it was possible to retrieve electricity consumption. This last figure is not completely satisfactory for a proper analysis. Furthermore it is difficult to retrieve to what extent the households in the survey are representative of the total population of households having a heat pump installed. On the other hand this is a condition when researching a case like households use of heat pumps. As it probably is less than 10% of the Danish house owners that has a heat pump installed, a normal representative survey among house owners would need several thousand respondents to include a reasonable number of households with a heat pump. Furthermore, retrieving actual electricity consumption of these households afterward would need contact with many different electricity companies and in reality not be possible. Based on these conditions it must thus be concluded that the material presented in this paper is the best possible and the conclusions, even though those related to summerhouses can only be indicative, are of high relevance.

These methodological challenges is also supported by review of literature showing that studies including energy consumption before and after installation of efficient technologies most often suffer from a rather low number of observations. From a recent review of literature on rebound effect including 12 studies of this kind, some of the reviewed studies included only 3, 13, 59 or 79 households whereas a few studies included some hundred households [1].

Conclusion

The overall research questions in this paper were to what extent installation of heat pumps in private households is followed by actual reduced electricity consumption or if changes in comfort practices would include a rebound effect and thus outweigh potential savings. Of special interest was the question if the heat pump was used for air conditioning and if this use could explain higher electricity consumptions than expected. From technical specifications of the effect of air-to-air heat pumps it should be expected that electricity for heating purpose is reduced by two third if the house was heated by direct electric heating before installation and only by the use of heat pump after installation (these calculations take into account reduced efficiency, COP, at low outdoor temperatures). If we assume that 64% of a households electricity use is used for heating, then it should be expected to see approximately 50% reduction of households' electricity consumption after installation of the heat pump.

Analyses of electricity consumption in 138 permanently occupied dwellings confirm that the amount of saved electricity is dependent on how the house is heated before and after installation of the heat pump. The highest average reduction was seen in households that primarily used direct electric heating before and primarily used heat pump after. Reduction in electricity consumption was here 2481 kwh/year corresponding to 18% reduction. The average reduction in electricity consumption for all 138 households is 1985 kWh/year, corresponding to 14% reduction. However, based on the regression analysis we showed that the heat pump alone accounted for a reduction of 35%. These analyses thus on one hand conclude that installation of air-to-air heat pumps do carry substantial energy reductions, though analysis also point out that these reductions are lower than what could be expected from a technical approach.

Survey analysis of 405 respondents confirms that households do change their comfort practices after having purchased a heat pump. First, we see a reduction in wood burning for households who are using wood as a supplement. Furthermore, there is evidence that some households raise their indoor temperatures after installing the heat pump and also that a minority of the households use it for air conditioning. Together these changes in fuel shifting and comfort practices might contribute to the explanation of why the assumed potential based on simplistic energy reductions are not reached in households who installed a heat pump.

Regression analysis on 138 households have been used to test to what extent these types of change in comfort practices can explain the differences in electricity consumption before and after the purchase of the heat pump. The analysis points out that the change in heating period contributes to the explanation together with variables related to general wealth, consumer behaviour and to change in heating practices. Installation and maintenance defects might potentially also contribute to reduced savings. However, the visual inspections in relation to the qualitative interviews (6 dwellings and 6 summerhouses) only revealed few examples of technical problems that might influence the efficiency of the heat pumps: In two cases there were a risk of thermal air short-circuit in relation to the condenser or evaporator respectively, which potentially could result in an estimated 10-20% increase in electricity consumption. In a third case, dirt on the evaporator could potentially increase energy consumption by app. 10%. No visual problems were observed in the other cases. Also, almost 60% of the survey respondents answer yes to the question whether they have regularly servicing for their heat pump (buyers of heat pumps from the electricity utilities are normally offered a yearly servicing scheme). Therefore, it can be expected that the heat pumps covered by this study in general have a high maintenance-standard. All in all, there are no indications of technical defects being an important factor.

Furthermore, it is interesting to follow how electricity consumption develops over time in the households having installed a heat pump. There seem to be a pattern where the first year after installation show an immediate reduction, which is followed by a small increase the next year and then a stable period in some years followed by a reduction again after some years. Even if it is difficult to explain this pattern satisfactorily, it indicates that differences in user practices strongly influence the energy savings that can be gained from installing heat pumps. The differences might also partly be due to degradation of performance due to maintenance faults such as restricted airflow, restricted refrigerant, condenser/evaporator coil blockage, low charge, etc. However, as already mentioned, the general maintenance-standard seem to be high for these air pumps making this a less likely explanation.

Finally, this study has also resulted in some interesting observations with regard to heat pumps installed in summerhouses. Although the data basis for summerhouses is limited, the results indicate some potentially problematic consequences of installing heat pumps in summerhouses. This is related to the habits of “closing down” the summer house in the winter period, frost-proofing the summerhouse in wintertime, or of maintaining an indoor temperature which is close to a comfort level, meaning that it is comfortable to arrive to the summerhouse if it occasionally is used in wintertime. Results show that often installation of an air-to-air heat pump in Danish summerhouses are connected to a change in these practices, and data suggest that a majority of those installing a heat pump in their summerhouse change habits and start to maintain a much higher indoor temperature during wintertime. Furthermore it is interesting to notice that most of the heat pumps sold to these summerhouses is not designed to have a lower temperature set point than 16 deg. C, which means that even though people might prefer to keep a lower indoor temperature this is not technically possible. Analysis of the electricity consumption in summerhouses confirms that there are no reductions in annual electricity consumption when installing heat pumps in summerhouses. Model calculations indicate that it costs more energy to maintain 16 C by the use of a heat pump than maintaining 5 C by the use of direct heating.

References

[1] Sorrell, S., Dimitropoulos, J. and M. Sommerville (2009) ‘*Empirical estimates of the direct rebound effect: A review*’, Energy Policy 37(4): 1356-71.

[2] Shove E. (2003) *Comfort, cleanliness and convenience. The social organization of normality.* Oxford: Berg.

[3] Statistics Denmark (2010) *Statistisk Årbog 2010*. Copenhagen: Statistics Denmark.

[4] Andersen, H.S. and M. Vacher (2009) *Sommerhuse i Danmark. Hvem har dem og hvordan bruges de?* Copenhagen: Center for Bolig og Velfærd.

[5] Hjalager, A. (2009) *Udviklingsdynamikker i sommerhussektoren*. Copenhagen: Center for Bolig og Velfærd.

[6] Kofoed, N., Rasmussen, E.R., Weldingh, P., Worm, J., Rasmussen, L.A., Reuss, M., Ellehauge, K., Kjærgaard, C., and O.M. Jensen (2010) *Elbesparelser i sommerhuse her og nu.* Hørsholm: Statens Byggeforskningsinstitut, Aalborg Universitet (SBi 2010:54)

[7] Dansk Energi (2010) *Dansk Elforsyning Statistik 2009*. Copenhagen: Dansk Energi.

[8] Wittrup, S. (2010) *’Fejldimensionerede varmepumper skæmmer markedet*”, Ingeniøren Energi & Miljø, 10 September 2010 (p. 3).

[9] Christensen,T. H, Gram-Hanssen, K., Petersen, P. E., Larsen, T. F., Gudbjerg, E., Rasmussen, L. S, Munter, P. 2011. Air-to-air heat pumps: A wolf in sheep's clothing. In "Energy efficiency first: The foundation of a low-carbon society" eceee 2011 Summer Study 6–11 June 2011, Belambra Presqu'île de Giens, France

[10] Levesque, R. SPSS Programming and Data Management: A Guide for SPSS and SAS Users, Fourth Edition (2007), SPSS Inc., Chicago Ill. PDF ISBN 1568273908

Appendix: Full regression analysis and t-test to determine which variable are significant.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	7767.307	23158.526		.335	.739
	Xbefore	.559	.068	.730	8.205	.000
	PrimaryAfter_not_elheat	-2012.748	1222.823	-.172	-1.646	.105
	PrimaryAfter_elheat	1066.528	925.510	.081	1.152	.254
	PrimaryBefore_not_elheat	3563.225	3899.641	.252	.914	.365
	PrimaryBefore_elheat	2417.948	3905.136	.175	.619	.538
	Adults	-461.929	603.701	-.048	-.765	.447
	Children	-59.842	441.250	-.010	-.136	.893
	House_size	16.239	10.657	.115	1.524	.133
	House_age	-4.933	12.102	-.025	-.408	.685
	Person_changes	1800.260	1365.837	.098	1.318	.193
	HeatedArea	-7.107	12.656	-.038	-.562	.577
	NewRooms	-3.142	21.338	-.010	-.147	.883
	Fireplace	-1022.652	887.956	-.096	-1.152	.254
	HeatPeriod_chng	-1016.633	533.758	-.119	-1.905	.062
	HeatTemp_increase	281.046	650.248	.028	.432	.667
	Cooling_days	85.050	80.368	.070	1.058	.294
	Appliances_chng	106.592	253.996	.031	.420	.676
	CFL	-1048.031	683.312	-.091	-1.534	.131
	Appliances_new	-216.478	686.176	-.022	-.315	.754
	Settopbox_new	36.928	633.955	.004	.058	.954
	TV_exstra	2297.504	812.431	.196	2.828	.006
	PC_extra	302.535	678.122	.029	.446	.657
	InsolateHouse	-544.083	795.562	-.045	-.684	.497
	Income_household	4.357	1.847	.180	2.359	.022
	Fireplace_instal	194.599	1946.206	.008	.100	.921
	Firewood_save	1119.234	875.294	.091	1.279	.206

Passive tubular daylight guidance systems, design methodology

CIUGUDEANU Călin, Ph.D. student[1], POP Florin[2], professor

[1] *Romproiect Electro SRL, Cluj-Napoca, Romania*
[2] *Technical University of Cluj-Napoca, Romania*

Abstract

Tubular daylight guidance systems are linear structures that channel daylight by means of optical interactions into the core of a building. They consist of a light transport section with, at the outer end, some device for collecting natural light and, at the inner end, a means of distribution of light within the interior. Collectors may be either mechanical devices that actively focus and direct daylight (usually sunlight), or be passive devices that accept sunlight and skylight from part or whole sky hemisphere.

The development, over the last decade, of materials with high specular reflectance has led to a large number of passive zenithal systems; the most commercially successful type of daylight guidance being installed in many parts of the world. Presently there are few methods of prediction of illuminance resulting from daylight guidance system output within a building.

The paper presents some of the design techniques based on CIE173:2006 “Tubular Daylight Guidance Systems – technical report”, as well as their application in a case-study for a passive TGCS installed in a residential building in Cluj-Napoca, Romania.

1. Introduction

The visual effect of lighting is an important part of the total living or working environment. Although every building has different functions, it is compelling to use daylight as a primary or a secondary light source for the benefits of energy, productivity, and health[1]. Although it is becoming increasingly difficult to provide the light required for various activities from daylight alone due to the increased building density, partial use of daylight can still significantly reduce lighting and cooling loads and improve occupants' preferences, visual relief, and pleasing effects[2].

The most effective daylighting strategies could be to optimize building orientation and form as well as to optimize window size and placement. Due to overcrowded urbanization, however, it is increasingly difficult to use strategies that let natural light penetrate deep into the interior space. Fortunately, emerging technologies are available that allow sunlight into the core interior of multistory buildings, although optical sunlighting systems as a remote illumination source can be traced back as far as the late 1800s [3]. A number of recent developments in optical lighting systems offer renewed opportunities for reliable optical daylighting sources with broad applicability and high effectiveness. And due to developments in renewable materials, the use of optical daylighting systems for active lighting control can be simple, reliable, and relatively inexpensive.

A number of systems exist to redirect daylight into areas of buildings that cannot be lit by conventional glazing. One major generic group is known as 'beam daylighting' - redirects sunlight by adding reflective or refracting elements to conventional windows. The second major group is known as 'tubular daylight guidance systems TDGS'.

Tubular daylight guidance systems are linear devices that channel daylight into the core of a building. They consist of a light transport section with, at the outer end, some device for capturing natural light

[1] Nicolow J. *Getting the green light from the sun - The benefits of daylight harvesting*. Construction Specifier 2004

[2] Cheung HD, Chung TM - *Calculation of the vertical daylight factor on window facades in a dense urban environment*. Architectural Science Review 2005

[3] Mirkovich DN. - *Assessment of beam lighting systems for interior core illumination in multi-story commercial buildings*. ASHRAE Transactions 1993;99(1)

and, at the inner end, a means of distribution of light within the interior. The light capture device may be located at roof level of a building enabling light from the zenithal region of the sky to be gathered. Alternatively, light may be gathered from a device mounted on the building facade. Zenithal openings allow intensive use of daylight but may cause glare or overheating due to penetration of direct solar radiation especially during summer. For a horizontal aperture the quantity of solar flux entering through a facade mounted collector depends on facade orientation and season and these systems are more likely to be influenced by external obstruction than zenithal systems. Collectors may be either mechanical devices that actively focus and direct daylight (usually sunlight), or be passive devices that accept sunlight and skylight from part or whole sky hemisphere. The transport element is usually a tube lined with highly reflective or prismatic material or may contain lenses or other devices to redirect the light. Light is distributed in an interior space by output components, commonly diffusers, made of opal or prismatic material[4].

There has been a considerable research effort on TDGS over the last decade. Initially, this concentrated on light transport materials and devices, but latterly, a number of methods of predicting light delivery and/or distribution within a building interior have been developed. They form the basis of CIE173:2006 Tubular Daylight Guidance Systems – technical report. The report describes mostly the passive zenithal systems. These are, by far, the most commercially successful types of tubular daylight guidance, being manufactured and installed in large numbers in numerous countries. The design methodology presented in this report relates to passive zenithal systems only. The Report includes reviews of the technology of all generic types of daylight guidance systems, and includes case-studies. The sections on performance indices, photometry of components and systems, design methods, cost and benefits, human factors and architectural issues relate to passive zenithal systems[4].

The paper presents results of an experimental study on the performance of a passive tubular daylight system, under the climatic condition of Cluj-Napoca, Romania. A light pipe with flat collector and light-distribution diffuser was installed in a residential building. The performance of the light pipe was tested. The CIE173:2006 suggested methods of prediction are tested against measured data from the installation survey.

2. CIE 173:2006 TDGS technical report - design techniques

The CIE technical report describes three prediction methods for routine design use. The methods differ in sophistication and are as well different requiring different amounts of input data. The designer can choose the appropriate method for a particular design problem, depending on the amount of data available and the desired accuracy. The first method is a tabular method which requires only knowledge of the space to be lit, its function and its geographic location. Results give an indication of the floor area that will be usefully lit per guide. The second method is based on the "standard daylight transfer characteristic". The third method permits prediction of likely light outputs from guide systems of different configurations based on tabulated data on guide efficiencies[4].

The technical report mentions as well some other design methods for passive zenithal systems, such as: SkyVision software package, the Lxplot package and the University of Liverpool semi-empirical method.

2.1 Approximate sizing method

This is a method of approximate sizing of passive tubular daylighting systems, based on local conditions. Sizing first depends on the function of the space to be lit: a windowless hallway will require less guide area than a bathroom, per square meter of floor area. The second parameter is the local climate. Three climate areas were chosen depending of the latitude. For instance, the northern areas (Area 0), need more tubes because the solar altitude is lower and overcast skies are darker. The third

---

[4] CIE 173:2006, *Tubular Daylight Guidance Systems*, CIE Technical Committee 3-38 of Division 3 "Interior Environment and Lighting Design", ISBN 3 901 906 49 5.

parameter is the length of the tube. This has little influence if the tube is straight, without bends, and if it is covered with extremely reflective coatings (reflection coefficient about 0.99)[4].

There are proposed some successive steps for sizing of passive daylight guidance systems. Sizing of a TDGS leads to the selection of a diameter of a tube and the number of tubes to use in the space. There is suggested the inverse coefficient: number of square-meters of space lit by TDGS. This can be obtained by following three easy steps. First it has to be selected the type of space to lit, second the geographic area from Figure 2.1 (this example covers only Central and Western Europe, more data can be obtained from the European Database for Daylight and Solar Radiation, www.satel-light.com) and third the estimation of the area to be lit. When line and columns are selected, find in Table 2.1 the value immediately higher for lighting with a single TDGS. If one tube is not enough, divide the surface to light by the highest value to get the number of tubes. After this, you can read the diameter of the corresponding tube(s) [4].

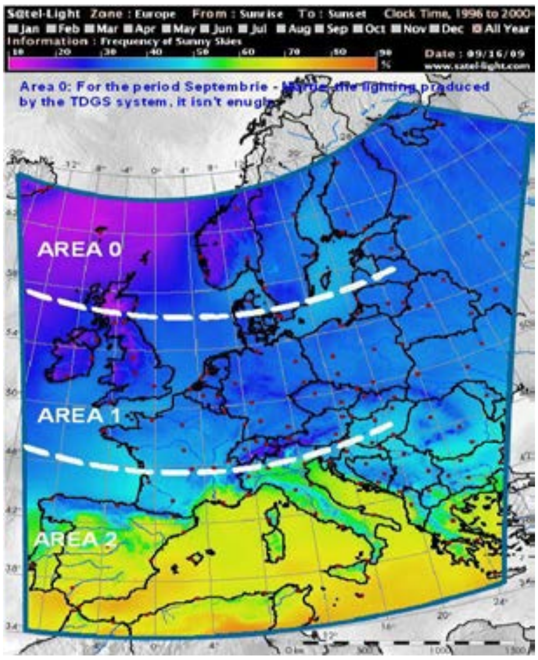


Figure 2.1 Climatic areas in Western Europe for assessment of daylight guidance systems (Source: www Satel-light.com)

Table 2.1 indicates which surface is fully lit by the TDGS on the basis of the following criteria: what is the destination of the area to be lit, diameter of the light guide and the geographic location.

If we define the aperture ratio as the ratio of the daylight guide section (m^2) and the area which is lit by the system, the Table 2.1 gives an indication of this ratio. Typically, aperture ratio is in the range of 1% to 3% of the ceiling area. This data should be compared with the state of the art in the sizing of roof-lights, from 4% to 10%, typically. As a first approximation, the guide should be sized at a third of the standard size of roof-lights. This is due to the much higher optical efficiency of the system.

Table 2.1 Area (per floor plan) illuminated by TDGS (gray cells indicate the economic optimum) [4]

		Diameter of Daylight Guidance System									
		0,250 m		0,350 m		0,375 m		0,530 m		0,650	
		0,049 m^2		0,096 m^2		0,11 m^2		0,22 m^2		0,33 m^2	
	Ceiling height	Geographical area		Geographical area		Geographical area		Geographical area		Geographical area	
		Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2
Underground car park	2,5 m	4,1 m^2	7,4 m^2	9,0 m^2	15,9 m^2 (0,6 %)	10,5 m^2 (1%)	18,6 m^2	22,5 m^2	40 m^2	35 m^2	62,1 m^2
Maintenance, warehousing premises	2,5 m	1,5 m^2	2,7 m^2	3,3 m^2	5,9 m^2	3,9 m^2	6,9 m^2	8,3 m^2	15 m^2	13 m^2 (2,5 %)	23,0 m^2
Circulation areas	2,5 m	2,6 m^2	4,6 m^2 (1,1 %)	5,6 m^2 (1,7 %)	9,9 m^2	6,5 m^2	11,5 m^2	13,9 m^2	25 m^2	22 m^2	38,5 m^2
Premises frequently occupied (under 30 m^2)	2,5 m	0,6 m^2	1,1 m^2	1,4 m^2	2,5 m^2	1,6 m^2	2,9 m^2	4 m^2 (5,5 %)	6 m^2 (3,6 %)	5,4 m^2	9,7 m^2
Premises frequently occupied (over 30 m^2)	2,5 m	0,8 m^2	1,4 m^2	1,7 m^2	3,0 m^2	2,0 m^2	3,5 m^2	4 m^2	7 m^2	6,5 m^2	11,6 m^2
Gymnasium, large warehouses	7,0 m	1,4 m^2	2,5 m^2	3,0 m^2	5,3 m^2	3,5 m^2	6,2 m^2	7,2m^2	13 m^2	11 m^2 (3,6 %)	20 m^2 (1,6 %)

During a normal day between the hours of 08:00 and 18:00 the guides will usually provide more light than specified in the electric lighting recommendations for such premises. The indicative optimal design (in terms of the necessary aperture ratio) is shown in parentheses against a grey background and is intended for rooms without any other daylight openings. Taking into consideration the destination of the area to be lit, the ceiling height and the geographical area, the CIE report shows the optimal device that should be used.

2.2 Daylight transfer characteristic method

For a given tubular light guide system, consisting of a daylight input window, a length L of light guide having a diameter, D and a light output window, the "standard light transfer characteristic" is determined as follows: a diffuse light source is placed near the input window, and the illuminance, E, is measured at the input window. The luminous flux leaving the guide output, Φ, is also measured. The "standard daylight transfer characteristic" is simply the ratio Φ/E which has units of m^2. This is the equivalent area of an open-sky aperture that would be needed to produce the same amount of light, if there were no losses in the system[4].

First there has to be estimated the typical outdoor global illuminance, E_d appropriate to the location. This data is usually in the form of the proportion of the year or of working hours, when a given external illuminance will be exceeded. The procedure for obtaining this information differs with country and design practice. Local design guidance for conventional daylight systems, for example will almost certainly contain this information. For Western and Central Europe the SATEL-LIGHT web server provides this information (www.satel-light.com).

The outdoor illuminance, E_d is multiplied by the standard daylight transfer characteristic to give the typical luminous flux output of the pipe. This can be conservatively assumed to be approximately diffuse and can be used as such in any lighting software or zonal cavity calculation. Very roughly, the internal illuminance will be the total luminous flux output of the pipes divided by the illuminated area.

Alternatively, using daylighting terminology we can estimate the "average daylight penetration factor", which, in analogy to traditional daylight factor, is the ratio of the average resultant illumination divided by E_d. This can be estimated as the sum of the standard daylight transfer characteristics divided by the illuminated area[4].

2.3 TDGS transmission efficiency method

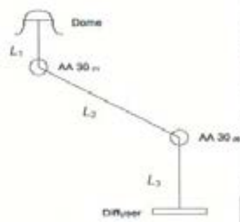
This calculation method is used as the basis of the methods described in Sections 2.1 and 2.2. It is applicable to a wider range of interiors than the other methods described and is applicable where standard daylight transfer characteristic data is not available.

The method is based on data shown in Table 2.2 which gives transmission tube efficiencies (*TTE*) of guides of various diameters, lengths and reflective properties. The method permits evaluation of performance of a wide range of configurations of passive guide system including the influence of bends. Note that since the lowest internal reflectance in Table 2.2 is 92%, it is not recommended that this method be used for design of systems with flexible light transport guides [4].

Table 2.2. The efficiency of systems with different diameters, lengths and reflective properties (CIE 173:2006) [4]. *TTE* - tube efficiency of transmission for natural light with cloudy sky, *R* - reflection coefficient, *L* - length, *D* - diameter. It is recommended that *TTE*> 0.4 for set length. If *TTE* <0.2 will chose a larger diameter tube or a higher reflexivity tube.

D→		25 (10")					35 (14)					37,5 (14,75")					53 (21")					65 (25,6")					90 (35,4")			
	L/D	Silver reflective films Alu anodized bright		visible mirror films		*L/D*	Silver reflective films Alu anodized bright		visible mirror films		*L/D*	Silver reflective films Alu anodized bright		visible mirror films		*L/D*	Silver reflective films Alu anodized bright		visible mirror films		*L/D*	Silver reflective films Alu anodized bright		visible mirror films		*L/D*	Silver reflective films Alu anodized bright		visible mirror films	
R→ *L*↓		0,92	0,95	0,98	0,995		0,92	0,95	0,98	0,995		0,92	0,95	0,98	0,995		0,92	0,95	0,98	0,995		0,92	0,95	0,98	0,995		0,92	0,95	0,98	0,995
0,25	1	0,93	0,96	0,98	1,00	0,7	0,95	0,97	0,99	1,00	0,7	0,95	0,97	0,99	1,00	0,5	0,97	0,98	0,99	1,00	0,4	0,97	0,98	0,99	1,00	0,3	0,98	0,99	1,00	1,00
0,5	2	0,87	0,92	0,97	0,99	1,4	0,90	0,93	0,98	0,99	1,3	0,91	0,94	0,98	0,99	0,9	0,93	0,96	0,98	1,00	0,8	0,95	0,96	0,99	1,00	0,6	0,96	0,98	0,99	1,00
1	4	0,78	0,84	0,93	0,98	2,9	0,82	0,87	0,95	0,99	2,7	0,83	0,88	0,95	0,99	1,9	0,87	0,92	0,97	0,99	1,5	0,90	0,92	0,97	0,99	1,1	0,92	0,95	0,98	1,00
2	8	0,58	0,71	0,87	0,97	5,7	0,67	0,76	0,91	0,98	5,3	0,69	0,78	0,91	0,98	3,8	0,77	0,85	0,94	0,98	3,1	0,80	0,85	0,95	0,99	2,2	0,85	0,91	0,96	0,99
3	12	0,45	0,60	0,81	0,95	8,6	0,56	0,66	0,86	0,96	8,0	0,58	0,69	0,87	0,97	5,7	0,68	0,78	0,91	0,98	4,6	0,72	0,79	0,92	0,98	3,3	0,79	0,86	0,94	0,99
4	16	0,35	0,51	0,76	0,93	11,4	0,46	0,58	0,82	0,95	10,7	0,49	0,62	0,83	0,95	7,6	0,60	0,72	0,88	0,97	6,2	0,65	0,73	0,90	0,97	4,4	0,73	0,82	0,93	0,98
5	20	0,27	0,44	0,71	0,92	14,3	0,39	0,51	0,78	0,94	13,3	0,41	0,55	0,80	0,94	9,4	0,53	0,67	0,85	0,96	7,7	0,59	0,67	0,88	0,97	5,6	0,68	0,79	0,91	0,98
6	24	0,21	0,38	0,67	0,90	17,1	0,32	0,45	0,75	0,93	16,0	0,35	0,49	0,76	0,93	11,3	0,47	0,62	0,82	0,95	9,2	0,53	0,62	0,85	0,96	6,7	0,63	0,75	0,89	0,97
8	32	0,13	0,28	0,59	0,87	22,9	0,23	0,35	0,68	0,91	21,3	0,25	0,39	0,70	0,91	15,1	0,37	0,53	0,77	0,94	12,3	0,44	0,54	0,81	0,95	8,9	0,55	0,68	0,86	0,96
10	40	0,09	0,21	0,52	0,84	28,6	0,16	0,28	0,62	0,88	26,7	0,18	0,32	0,64	0,89	18,9	0,29	0,46	0,73	0,92	15,4	0,36	0,46	0,77	0,94	11,1	0,47	0,62	0,83	0,95
12	48	0,05	0,16	0,46	0,82	34,3	0,12	0,22	0,57	0,86	32,0	0,13	0,26	0,59	0,87	22,6	0,23	0,40	0,68	0,91	18,5	0,30	0,40	0,73	0,92	13,3	0,41	0,57	0,90	0,94
14	56	0,04	0,12	0,40	0,79	40,0	0,09	0,17	0,52	0,84	37,3	0,10	0,21	0,54	0,85	26,4	0,19	0,34	0,64	0,89	21,5	0,25	0,35	0,70	0,91	15,6	0,36	0,52	0,77	0,94
15	60	0,03	0,10	0,38	0,78	42,9	0,07	0,15	0,50	0,83	40,0	0,09	0,19	0,52	0,84	28,3	0,17	0,32	0,62	0,89	23,1	0,23	0,32	0,68	0,91	16,7	0,33	0,50	0,75	0,93
16	64	0,02	0,09	0,36	0,76	45,7	0,06	0,14	0,47	0,82	42,7	0,07	0,17	0,50	0,83	30,2	0,15	0,30	0,60	0,88	24,6	0,21	0,30	0,66	0,90	17,8	0,31	0,48	0,74	0,93
18	72	0,01	0,07	0,32	0,74	51,4	0,05	0,11	0,43	0,80	48,0	0,05	0,14	0,46	0,82	34,0	0,12	0,26	0,57	0,86	27,7	0,17	0,26	0,63	0,89	20,0	0,27	0,44	0,71	0,92
20	80	0,01	0,05	0,28	0,71	57,1	0,03	0,09	0,40	0,79	53,3	0,04	0,11	0,42	0,80	37,7	0,10	0,22	0,54	0,85	30,8	0,14	0,23	0,60	0,88	22,2	0,24	0,40	0,69	0,91
25	100	0,00	0,03	0,21	0,66	71,4	0,02	0,05	0,32	0,74	66,7	0,02	0,07	0,34	0,75	47,2	0,06	0,16	0,46	0,82	38,5	0,09	0,16	0,53	0,85	27,8	0,17	0,33	0,63	0,89

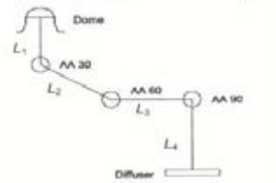
Global efficiency (*EG*) of TDGS components lined with multilayer aluminium (98%<*R*<99,5%) including bends 0° - 30° - 60° - 90°. Optical equivalent lengths measured on single components using the protocol described in Section 3 of this Report. Test conducted at CSTB - Nantes.



D	∅ 250		∅ 375		∅ 530		∅ 650	
Li - M	Li	M	Li	M	Li	M	Li	M
L_1 / M	0.5	2	1	2.7	2	3.8	1	1.5
L_2 / M	2	8	1.5	4	0.5	0.9	2	3.1
L_3 / M	2	8	3	8	4	7.6	5	7.7
AA 30 / M	0,30	4.8	0,30	3.5	0.40	2.3	0.40	1.4
AA 30 / M	0.30	4.8	0,30	3.5	0.40	2.3	0.40	1.4
Σ Li / Σ M	5.1	27.6	6.1	21.7	7.3	16.9	8.8	10.1
EG%		48		49		52		53

Aspect ratio M of		∅ 250	∅ 375	∅ 530	∅ 650
	30	4.8	3.5	2,3	1.4
	60	9.6	5,7	4,5	2.8
	90	12,8	7,2	5.8	3.7
	2 x 30	8.7	3,8	2.5	1.5
	2 x 90	12.9	6.8	7.0	3.6

D - diameter;
L - length;
M = *L/D* Direct aspect ratio and optical equivalent when *L* is the optically equivalent, deducted by efficiency test.



D	∅ 250		∅ 375		∅ 530		∅ 650	
Li - M	Li	M	Li	M	Li	M	Li	M
L_1	1	4	1,5	4	2	3,8	0,5	0,8
L_2	2	8	1	2,7	0.5	0.9	1	1.5
L_3	2	8	2,5	6,6	4	7,6	3	4.6
L_4	1.5	6	2	5.3	0.5	0.9	4	6.1
AA 30	0,30	4,8	0.30	3,5	0.40	2,3	0,40	1,4
AA 60	0.60	9,6	0,60	5,7	0.80	4,5	0.80	2.8
AA 90	0.60	12,8	0,60	7,2	1,20	5,8	1,20	3,7
Σ Li / Σ M	8	53.2	8.5	35	10.9	25.8	10.9	20.9
EG%		32.4		44		46		49

Figure 2.2. The values of overall efficiency [4].

The approach considers tubular daylight guidance system (TDGS) output devices as flush mounted luminaires having an approximate cosine luminous intensity distribution for which tabulated values of useful downward flux apply, and since there is no upward luminous flux, these values can be used directly as Utilization Factors for design purposes. The Lower Flux Utilance and the appropriate Maintenance Factor (*MF*) for TDGS output devices are shown in Table 2.3.

Table 2.3 Utilisation (a) and maintenance (b) factors for TDGS[4].

(a)

Room index	Effective ceiling reflectance (%)	Reflectance of floor or working plane 10% Reflectance of wall 50%	30%	10%	0	Reflectance of floor or working plane 30% Reflectance of wall 50%	30%	10%	0
0,8	70	0,51	0,43	0,37	0,34	0,54	0,44	0,37	0,35
	50	0,49	0,42	0,36	0,34	0,52	0,43	0,37	0,35
	30	0,48	0,41	0,36	0,34	0,50	0,42	0,37	0,34
1,0	70	0,57	0,49	0,43	0,40	0,61	0,51	0,44	0,41
	50	0,55	0,48	0,42	0,40	0,58	0,50	0,43	0,41
	30	0,54	0,47	0,42	0,40	0,56	0,49	0,43	0,40
1,25	70	0,63	0,55	0,49	0,46	0,68	0,59	0,51	0,48
	50	0,61	0,54	0,49	0,46	0,65	0,57	0,50	0,47
	30	0,59	0,53	0,48	0,46	0,62	0,55	0,49	0,47
1,5	70	0,68	0,60	0,54	0,52	0,74	0,64	0,57	0,54
	50	0,66	0,59	0,54	0,51	0,70	0,62	0,56	0,53
	30	0,64	0,58	0,53	0,51	0,67	0,60	0,54	0,52
2,0	70	0,75	0,68	0,62	0,59	0,83	0,74	0,66	0,63
	50	0,72	0,66	0,61	0,59	0,78	0,70	0,64	0,61
	30	0,70	0,65	0,60	0,58	0,74	0,68	0,62	0,60
2,5	70	0,80	0,73	0,68	0,65	0,89	0,80	0,73	0,70
	50	0,77	0,71	0,67	0,65	0,83	0,76	0,70	0,68
	30	0,75	0,70	0,66	0,64	0,79	0,73	0,68	0,66
3,0	70	0,83	0,77	0,72	0,70	0,93	0,85	0,79	0,76
	50	0,80	0,75	0,71	0,69	0,87	0,81	0,75	0,73
	30	0,78	0,74	0,70	0,68	0,82	0,77	0,73	0,70
4,0	70	0,88	0,83	0,78	0,76	0,99	0,92	0,86	0,84
	50	0,85	0,81	0,77	0,75	0,93	0,87	0,83	0,80
	30	0,83	0,79	0,76	0,74	0,87	0,83	0,79	0,77
5,0	70	0,91	0,86	0,82	0,80	10,0	0,97	0,92	0,90
	50	0,88	0,84	0,81	0,79	0,97	0,92	0,87	0,85
	30	0,86	0,83	0,80	0,78	0,91	0,87	0,83	0,82

(b)

Room function	Exposure	Slope of glazing: Vertical, Rural/ suburban	Vertical, Urban	Inclined, Rural/ suburban	Inclined, Urban	Horizontal, Rural/ suburban	Horizontal, Urban
Residential: Private rooms and communal areas, few occupants, good maintenance, no smoking	Driving rain exposure	0,98	0,95	0,94	0,88	0,88	0,76
	Normal exposure	0,96	0,92	0,92	0,84	0,88	0,76
	Heavy snow exposure	0,96	0,92	0,88	0,76	0,84	0,68
	Sheltered by overhang	0,88	0,76	-	-	-	-
Commercial, educational: Rooms used by groups of people, areas with office equipment or smoking	Driving rain exposure	0,98	0,95	0,94	0,85	0,88	0,7
	Normal exposure	0,96	0,9	0,92	0,8	0,88	0,7
	Heavy snow exposure	0,96	0,9	0,88	0,7	0,84	0,6
	Sheltered by overhang	0,88	0,7	-	-	-	-
Polluted and heavily used rooms: Swimming pools, gymnasia, industrial areas or heavy smoking	Driving rain exposure	0,92	0,9	0,76	0,7	0,52	0,4
	Normal exposure	0,84	0,8	0,68	0,60	0,52	0,4
	Heavy snow exposure	0,84	0,8	0,53	0,4	0,36	0,2
	Sheltered by overhang	0,52	0,4	-	-	-	-

More detailed steps to be followed for this method are described in Section 4.2.

3. Case-study - passive TDGS installed in Cluj-Napoca

The experimental set up was located in a residential house from Cluj-Napoca, Romania. A light pipe produced by the Velux Company was mounted inside a 4 * 4 m room on the first floor of the building, as shown in Figure 3.1. The house is part of a duplex situated in Cluj-Napoca. The cylindrical light pipe has a length of 2.5 m and a diameter of 350 mm. A highly reflective film is laminated, using adhesives, to the interior surface which has a minimum reflectivity of 95%. The top of the pipe was sealed with a clear anti-yellowing acrylic plate. A pearl white diffuser was fitted to the lower opening of the light pipe for even light distribution within the room.

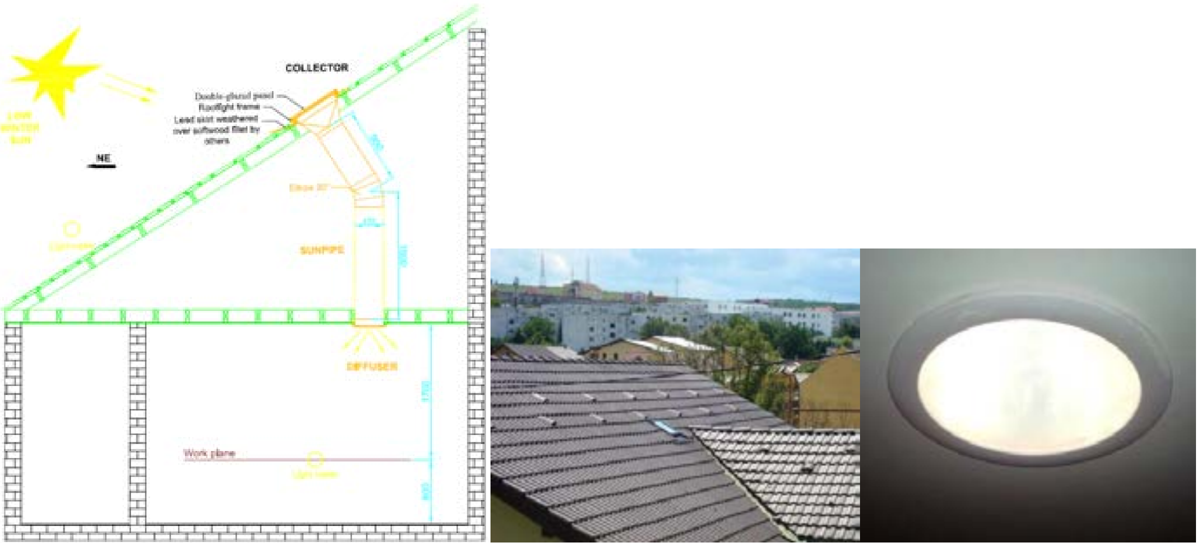


Figure 3.1 The experimental set up - Velux TWR14 installed in Cluj-Napoca, Romania

Illuminance measurement was carried out using a standard light meter which had a range of 0.05-100,000 lx. The meter was based on a photovoltaic cell which has a spectral response similar to that of a standard human eye thus avoids the need for correction for various types of light sources.
Illuminance of the sun on the open field, and that within the working plane inside the room, were obtained using two separate photocells. The readings were recorded manually and cares were taken to ensure that there were no passing clouds or other significant changes of lighting condition between reading the two cells. The photocell within the room was normally placed right under the diffuser, at a 0.8 m distance above the floor where the working plane is assumed to be. The data was measured in 30 different days, all around the year 2009. The collector is unfortunately facing the NE direction. Moreover there are some shading problems when the sun is low. That is why most of the presented results are around noon, in order to eliminate these errors.

Analyzing the measured data there can be calculated the maximum, minimum and average values of the indoor and outdoor illuminance. The results are presented in Table 3.1. For some winter days the results were not conclusive because the collector was covered with a layer of ice and snow. This should ask for second thoughts regarding the shape, geometry and orientation of the flat-type collectors, at least for northern areas with heavy winters.

Table 3.1 Measurements average results

Value	Internal illuminance (work plane)	External illuminance	Internal/ external illuminance	Average internal iluminance /day
	lx	lx	%	lx
Max	238	88000	1.38	206
Min	34	3200	0.19	65
Average	151	41926	0.36	145

The maximum illumination achieved for the work plan was 238 lx, for the day 31.07.2009, at 13.45, corresponding to a value of external illumination of 80,000 lx. This value does not coincide with the maximum recorded external illumination, about 88 000 lx (21.07.2009, time 13.55), probably due to measurement errors. The lowest illumination value on the work plan was 34 lx registered on 04.02.2009, 14.15, overcast conditions and coincides with the minimum outdoor illumination of 3200 lx. In general the system has provided an average illumination of about 145-150 lx, with an average ratio of indoor per outdoor illumination of about 0.36.

4. Analysis of the Velux system installed

For the above described passive TDGS system, there were made some designing evaluation remarks regarding CIE TDGS Technical report, described above. The first and the third design method were studied. The second design methodology could not be competed due to the experimental set ups needed. Additionally some simulations were made using the DIALux software.

4.1 CIE - Approximate sizing method

For the approximate sizing method there were followed the steps suggested by CIE report.

Step 1: Select the destination area that is intended to be illuminated. As mentioned above, the destination space was a relaxation room for chatting and watching television. The room was placed according to Table 2.1 in the category frequently occupied under 30 m^2.

Step 2: Select geographic area (more information can be obtained from the European Database for Natural light and solar radiation, www.satel-light.com). According to Figure 2.1, Romania and the city of Cluj-Napoca is fitted in Area 2.

Step 3: Estimating the surfaces that are intended to be intensely illuminated (by selecting the line and column in Table 2.1, select the next higher value of the surface, illuminated by a single TDGS). If a system is not enough, it will divide the area to be illuminated at the highest value to obtain the necessary systems. For our case of study involving only one TDGS system, we chose an area of 2.25 m^2, for the space above the room table and the sofa, as seen in Figure 4.1.

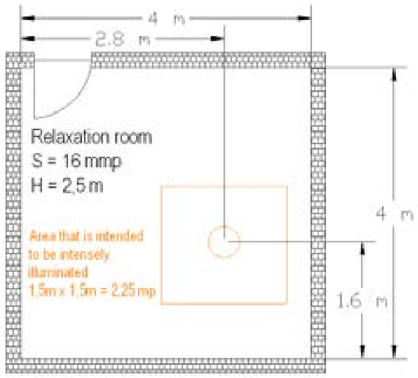


Figure 4.1 Choosing the surface intense illuminated

Step 4: Read the appropriate parameter of the system / systems according to Table 2.1.
It can be seen that our system provide sufficient natural light only for the space above the table. If there is intended to lit the whole room at the same illumination level (around 16 m^2), it would take approx. 6-7 systems of this kind, which would be an inadequate technical/economical solution. In this case, the selection of larger diameter systems is required.

4.2 CIE - TDGS transmission efficiency method

The method is applicable to a wider range of interior space than the method described above. The calculation is based on data presented in Section 2.3, in tabular form, indicating the transmission efficiency of the tube (TTE) for systems of different diameters, lengths and reflective properties. The method allows the assessment of the performance of a wide variety of configurations of passive tubular transport systems of light, including the influence of curvature.

The Velux TWR14 installed system configuration is shown in Figure 4.2. The tube has an internal reflectance of 95%.

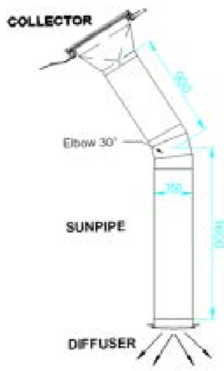


Figure 4.2 Velux TWR14 installed system configuration

The steps suggested by the CIE report for this method are as follows:

Step 1: Calculate the aspect ratio L / D (M) for straight pipes with no bends. Aspect ratio values for the system in question are presented in Table 4.1. The aspect ratios will be add up for the whole system (ΣM).

Table 4.1 Calculation of the amount of rations for the whole system, according to Figure 2.2

D	**Φ 350**	
L_i - M	L_i	*M*
L_1 / M	0.9	2.57
L_2 / M	1.6	4.57
AA30(1) / M	0,30	3.50
$\sum L_i$ / $\sum M$	2.5	10.64

Step 2: It is assumed a combined transmittance of a clear collecting dome and diffusing output device equal to 0.63.
According to Table 2.3 (b), choose the appropriate maintenance factor (*MF*). In this case *MF* = 0.76, for collectors inclined plane having a good maintenance residential areas located in the city.
Knowing the tube diameter and type of internal reflective material, *TTE* can be read in accordance with Table 2.2, for the sum of the rations. Velux system TWR14 diameter is 350 mm and the reflectivity is 95%. With these values and the ration based on the sum (10.64) results *TTE* = 0.615.
The overall efficiency of the Velux TWR14 system installed:

$$EG = TTE \times 0{,}63 \times MF \qquad (4.1)$$

By replacing the chosen values, we get EG = 0.615 x 0.63 x 0.76 = 0.2945.

Step 3: Knowing the light pipe section:

$$A = \frac{\pi \cdot D^2}{4} \qquad (4.2)$$

and exterior lighting E_h, we can calculate the total flux of light entering the tube, Φ_e:

$$\Phi_e = E_h \cdot A \ \ [\text{lm}] \qquad (4.3)$$

Total luminous flux emitted by the inner system is:

$$\Phi_i = \Phi_e \cdot EG \ \ [\text{lm}] \qquad (4.4)$$

Step 4: The final step is to analyze the distribution of light within the interior. The most usual requirement is for some average illuminance or daylight penetration factor DPF across the working plane. One convenient method of doing this is to use the concept of Utilization Factors for passive light guides[5]. The method is based on the determination of the total luminous flux reaching the work plane made up of a component that comes direct from the luminaire and an indirect component that reaches it after multiple reflections from the room surfaces. Passive TDGS are considered output devices as flush mounted luminaires having an approximate cosine luminous intensity distribution for which tabulated values of useful downward flux apply, and since there is no upward luminous flux, these values can be used directly as Utilization Factors for design purposes. The Lower Flux Utilance for TDGS output devices is shown in Table 2.3 (a), according to the reflectivity of the side walls, ceiling, floor and room index (k).

$$k = \frac{l \cdot L}{h(l + L)} \qquad (4.5)$$

Where: *l* is the width of the room, *L* - its length and *h* – the height of the working plane. For our case of study, *k = 1.11*. The ceiling and side walls are painted matte white with an estimated reflectance of 50% and the floor (work plan) 30%. The utilization factors for TDGS read from the Table 2.3 (a) is *UF* = 0.65.

The average working plane daylight penetration factor (*DPF*) for an installation with *N* systems is:

$$DPF = \frac{N \cdot \phi_i \cdot UF}{A \cdot E_h} \ \ [\%] \qquad (4.6)$$

For a value of 40 000 lx of the external illumination, *DPF* = 0.63% is achieved.

The calculated efficiency of the Velux TWR14 – passive TDGS is 29%.

$$\eta = \frac{\phi_i}{\phi_e} \qquad (4.7)$$

All the calculated results described above are presented in the Table 4.2. The data shows the comparative results for the lowest and the highest average illumination measured for the working plane. The system efficiency for the two input data is in around 29.5%.

[5] Carter D.J., *The measured and predicted performance of passive solar light guide systems*, Lighting Research and Technology, 34 (1), 2002

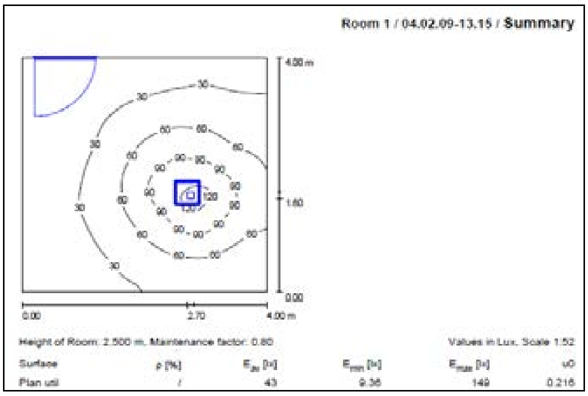
Table 4.2 Results of Excel spreadsheet - Velux TWR14 modeling system according to CIE

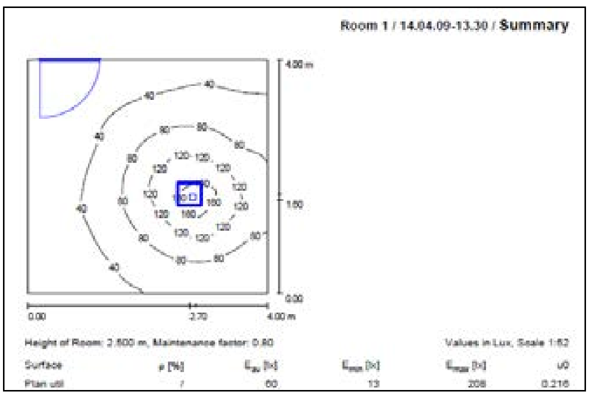
Diameter D	0.35	m	Diameter D	0.35	m
Exterior illumination Eh	3200	lx	Exterior illumination Eh	40000	lx
TTE	0.6150		TTE	0.6150	
MF	0.7600		MF	0.7600	
EG	0.2945		EG	0.2945	
Area	0.0963	m2	Area	0.0945	m2
φe	308.01	lm	φe	3850.18	lm
φi	90.70	lm	φi	1133.73	lm
Length L	4	m2	Length L	4	m2
Wide l	4	m	Wide l	4	m
Height h	1.7	m	Height h	1.7	m
Room index k	1.11		Room index k	1.11	
Utilization Factor UF	0.61		Utilization Factor UF	0.61	
Maintenance factor UF	0.76		Maintenance factor UF	0.76	
Computing area	2.5	m2	Computing area	2.5	m2
Average illuminatio work	18	lx	Average illuminatio work	221	lx
plan Eav			plan Eav		
DPF	0.69	%	DPF	0.69	%
System efficiency	29.447	%	System efficiency	29.446	%

4.3 DIALux 4.7 Predictions for the passive TDGS installed in Cluj-Napoca

DIALux 4.7 is well known among specialized software used in the calculation of interior and exterior lighting. Version 4.7 has in addition to the previous versions, the possibility to calculate the contribution of natural light inside a room. Besides the well known interior artificial lighting systems, software includes for now only some conventional daylight systems such as windows and skylights. To achieve a simulation model close to the one studied and described above, it was used a skylight with the same geometric and structural features as the Velux TWR14 system. Although rectangular with no bends, the used section, the length of the tube and its reflection coefficient were identical. The same features and optical properties were chosen for the glass (equivalent to the collector and diffuser together). This has some implications in terms of light distribution within interior, but the overall efficiency of the collector and diffuser is identical to that of the TDGS system installed, in order not to alter the overall efficiency. The reflection coefficient for the internal surfaces, the geometry and the location of the skylight inside the room, fully respects the experimental arrangement. Also for the geographical location the software allows to choose precisely the same latitude and longitude, orientation and inclination of the collector glass for admitting the natural light. Similar the same date and time was selected as the measurements were made, to make possible to determine the software accuracy.

The calculation was performed only using the amount of indirect natural light and it was set not to take into account the direct sun rays, which would of have a big impact onto the light distribution within interior. Four different days of the year have been selected, identical to those when the experimental recordings were made, in order to compare results. In Figure 4.3 there are presented the overall results of the calculations. It was attempted a comparison of the maximum illumination of the working plan, corresponding to the measured values on the work plan under the diffuser.





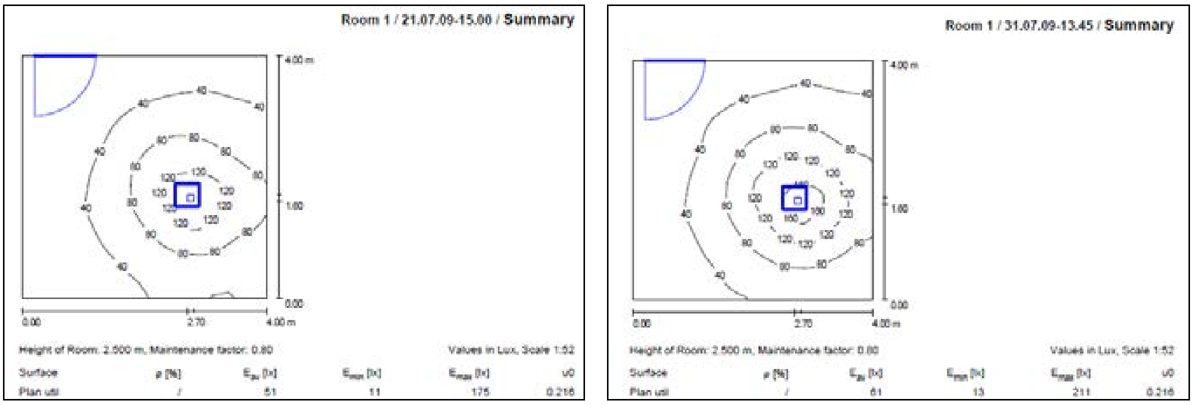


Figure 4.3 Simulation results with DIALux software - four different days

Table 4.3 presents the compared illumination measured levels and simulated levels with the software DIALux 4.7, for the maximum horizontal illuminance on the work plane. The average relative error is about 8.7%, but note that data are comparable just for overcast simulations. The fourth row has an error in the opposite direction than the others. This may be caused by the changing of the overcast sky conditions (between the inside and outside measurements). The measured average illuminance for the date of 30 and 31 of July around 13.30 o'clock shows the value of 204 lx. This value should lead to a relative error of 3% and an average relative error about 6.5%.

Table 4.3 Comparison results for the maximal horizontal illuminance – measured and simulated

Date	Time	Measured illuminance	Simulated illuminance	Relative error
		lx	lx	%
04/02/09	13:45	135	149	9
14/04/09	13:30	200	208	4
21/07/09	15:00	160	175	9
31/07/09	13:45	238	211	13
Average relative error				**8.7**

It was also simulated the lighting distribution on the floor plan, for the day 31.07.2009, at 13:45. The results, Figure 4.4, are comparable both as values and as illuminance levels. As expected, there are certain differences because of the measurements errors or the assimilations that were made using the DIALux software.

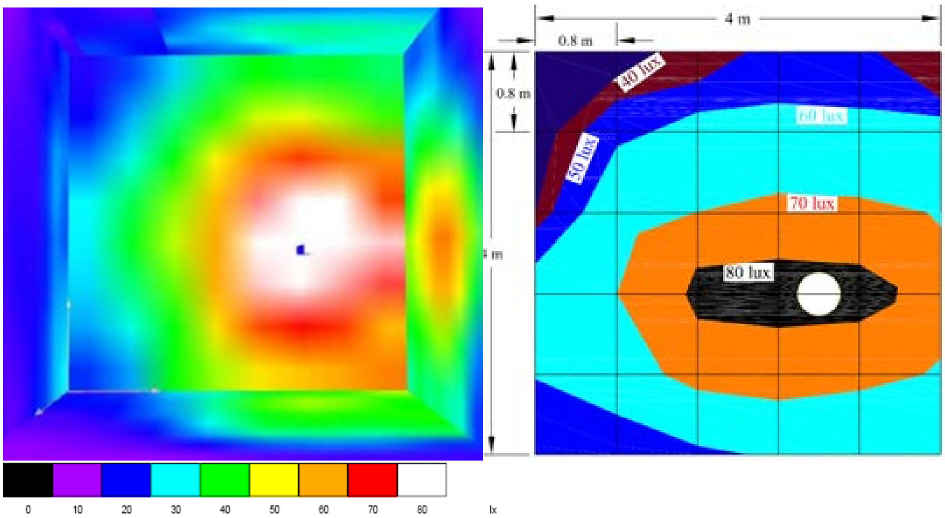


Figure 4.4 Comparison results for the simulated (left) and measured (right) illuminance levels 31.07.2009 - 13:45

It can be concluded that simulated daylight calculation results with DIALux 4.7 are quite accurate Soon it is expected that this software specialized in lighting calculations to include a TDGS module specifically dedicated, as recent versions have begun to pay increased attention to natural lighting.

5. Conclusions

Daylighting systems require a specific conception, very close related to the geographic context where they are built, to environment (natural and artificial obstructions), to impose levels of visual comfort and to climate.

The development of new materials with better performance in light reflection and transmission has lead to various solutions of energy efficient lighting systems able to grow potential for future applications.

Any technical and economical analysis of these systems must take into account both energy efficiency, and visual comfort conditions for the lighted spaces. For example, these solutions present outstanding possibilities to improve visual comfort in underground spaces, which are energy efficient due to low thermal losses[6].

Perspectives offered by these design solutions for the passive tubular daylight guidance systems lead to a higher visual comfort and to new possibilities of space utilization.

References

[1] Nicolow J. *Getting the green light from the sun - The benefits of daylight harvesting*. Construction Specifier 2004

[2] Cheung HD, Chung TM - *Calculation of the vertical daylight factor on window facades in a dense urban environment*. Architectural Science Review 2005

[3] Mirkovich DN. - *Assessment of beam lighting systems for interior core illumination in multi-story commercial buildings*. ASHRAE Transactions 1993;99(1)

[4] CIE 173:2006, *Tubular Daylight Guidance Systems*, CIE Technical Committee 3-38 of Division 3 "Interior Environment and Lighting Design", ISBN 3 901 906 49 5.

[5] Carter D.J., *The measured and predicted performance of passive solar light guide systems*, Lighting Research and Technology, 34 (1), 2002

[6] Ciugudeanu C, Pop F., *Tubular daylight guidance systems - Energy Saving Potential in Residential Buildings in Romania*, International Conference ILUMINAT 2009, Cluj-Napoca

[6] Ciugudeanu C, Pop F., *Tubular daylight guidance systems - Energy Saving Potential in Residential Buildings in Romania*, International Conference ILUMINAT 2009, Cluj-Napoca

Measuring the Impacts of Social Marketing – What is the "Bang for the Buck"? Is it Worth It?

Lisa A. Skumatz, Ph.D., Skumatz Economic Research Associates, Superior, CO, USA
D. Juri Freeman, Skumatz Economic Research Associates, Superior, CO, USA.

Abstract

The authors share the final results of a grant project in Colorado designed to fill the "gaps" in existing social marketing research and literature. While there have been decades of research into social marketing, data on impacts per dollar spent, behavior retention, and the cost effectiveness of social marketing compared to other programs is often limited or omitted in studies.

The project involved careful experimental design using three groups (a control, a full social marketing outreach group, and a limited outreach group) to measure the actual impacts of education on behavior change, the costs per kWh saved/ton of GHG reduced, and the retention of the behavior. Messages were crafted and delivered to impact energy behaviors and recycling/diversion. The presentation will cover the design and delivery of the project and resulting campaigns. Most importantly, the authors will report results including: 1) detailed analysis of the costs to conduct the campaign 2) estimated returns (energy saved, behaviors changed) for the investments 3) retention of the behavior change. We will also compare the incremental impacts of various levels of outreach and their impacts to allow program managers and decision-makers to determine what impacts may result from varying levels of outreach.
The presentation will help attendees answer an important question surrounding social marketing- is the cost of the outreach worth the effort? By comparing three distinct groups and the impacts of social marketing on their energy and trash related behaviors, this presentation helps fill in the "gaps" missing in the current literature.

Introduction and Review / Literature Review of Social Marketing

Behavioral changes targeting energy efficiency have the potential to realize energy savings of 25-30% in the United States (ACEEE). With this in mind, utilities and program managers are looking at techniques to effectively and efficiently change consumer behavior regarding energy consumption. Among the methods being used is "social marketing".

Social marketing,[1] or community-based social marketing (CBSM) has been receiving growing attention for the last 15-20 years. This strategy (with leading proponents Doug McKenzie-Mohr and William Smith) argues that engaging personal commitments, social interaction, pledges, and other personal responsibility elements to achieve behavioral change can be more effective than traditional broad-based, impersonal advertising. These techniques have been integrated into outreach in the fields of hazardous waste, recycling, and health for some time. With the increasing focus on the link between energy efficiency and greenhouse gas and increasing familiarity of these techniques in related fields, the funders of energy efficiency marketing campaigns are more frequently asking implementers to consider social marketing when developing their campaigns. Social marketing approaches recommend structuring programs based on five key elements:

- commitments to behavioral change (written commitments, public or group commitments, active involvement, leveraging from existing points of contact, helping people view themselves as concerned);

[1] This discussion is based on "*Social Marketing: Evaluating the Social Twist on Marketing Programs", AESP Strategies Article, Spring 2009, by* Lisa Skumatz, Carol Mulholland, and Sharyn Barata

- prompts (noticeable, self-explanatory, proximate, encouraging);
- norms (evolution of visible community norms, reinforced by personal contact);
- incentives (paired to behavior, rewarding, visible, monetary and non-monetary); and
- Communication (credible, well-framed, personalized, memorable, goal-oriented, feedback-providing) to effect changes and participation.

CBSM literature implies that programs based on this approach provide greater participation and behavior change, penetration to previously unconverted participants, and greater retention of the behavioral change. As part of a grant project conducted for the Colorado Department of Public Health and the Environment (CDPHE), the authors conducted a detailed literature review of CBSM literature.[2] Our review found that some efforts had been made to evaluate CBSM and non-traditional campaigns in recycling, hazardous waste, and limited work in energy. The most common type of social marketing program case studies found were health related (26%). However, nearly one fifth of all of the case studies researched were related to trash, recycling and/or composting and 15% of the case studies reviewed were related to energy use and efficiency. Some of the best-documented and well-known social marketing research projects have been conducted in the energy field. Unlike some of the other sectors addressed through social marketing, energy allows for slightly easier reporting of impacts. It is relatively simpler to report on reductions in kWh compared to a reduction in teen drinking. The range of behavior modification applications is fairly wide. These studies found strong shifts in purchase intentions for showerheads and water heaters using social marketing approaches; increases in recycling (and decreases in barriers or cleaner recyclables) from door-to-door approaches or specialized social marketing education campaigns, and impressive increases in comprehension and behavior change related to hazardous waste when CBSM approaches were applied.[3]

However, the quantitative work was far from plentiful and, with only a few exceptions, suffered from some of the same problems as evaluations of traditional education / advertising campaigns – small sample sizes, limited use of well-defined control groups, and similar issues.[4] Most importantly, we found the following.

- **No cost-effectiveness information**: The studies may have provided information on impacts, or may have provided a little cost information, but virtually none provided both, making it impossible to compare the cost-effectiveness of CBSM with other outreach, measure-based, or behavioral programs.
- **No persistence / retention information**: In addition, the studies lacked follow-up that would provide information on persistence of behavioral changes, knowledge, or other impacts from the CBSM initiative. Without an idea of the persistence of the measure, an appropriate figure for cost-effectiveness cannot be estimated because it would be unclear how long the savings generated by the project's budget could be expected to last.

With the goal of overcoming the existing shortcomings in the literature, the authors undertook a study of social marketing using experimental design in Broomfield, Colorado. Funding for this project was

---

[2] There are multiple college level textbooks written on the subject (Kotler and Lee 2008, Andreasen 1995, McKenzie-Mohr 1999, Andreasen 2000) and scores of websites, companies, consultants and careers dedicated to social marketing. Acknowledging this existing base of knowledge, Skumatz Economic Research Associates (SERA) focused on case studies of social marketing in real world practice. We used the case studies to update our previous literature review (Skumatz and Green 2000).

[3] The most successful elements of the case studies were integrated into the social marketing based outreach campaign for the project. The outreach plan was designed to be fluid, with portions of the message being influenced by early results of the project. For instance, the focus groups and survey results in the early stages of the project directly influenced how the rounds of outreach messages were crafted. The literature review provided suggestions on possible sources for background data collection. This was used to advise our activities.

[4] This is consistent with advertising in general, where a majority of the investment in evaluation of product advertising is done before the customer even sees a single ad. Many advertisers spend the bulk of evaluation funds perfecting the message and they use focus groups and other methods to determine what constitutes a memorable ad.

provided by the Colorado Department of Public Health and Environment (CDPHE) through the Advanced Technology grants program. Included in the goals of the grant, beyond the study of social marketing impacts, was an element of technology transfer, which included webinars and a development of a “toolkit” to share the social marketing techniques of the project with other communities in the state.

Experimental Design

The experimental design involved two test areas and a control neighborhood in Colorado’s Front Range (just east of the Rocky Mountains), all with similar demographics, services, status, location, and household characteristics. All were part of the same home owner’s association (HOA). Given the broad purview of the state client[5], the outreach and education was designed to impact both energy and recycling/diversion behaviors. This project, unlike many of the case studies that can be found in the literature, also addresses the historically underserved question of behavior retention- how long after the outreach do residents continue to partake in the desired behavior?

The three routes received different treatments, allowing us to test the impact of social marketing materials (which address barriers, connect to their norms, etc.) separately from the impact of the combination of these materials PLUS door-to-door and phone conversations. All households were measured for baseline behaviors using an energy / attitudes / behaviors survey plus measurement of their recycling and trash.

Table 1: Experimental Design for the CBSM Project

Route	Treatment
Route 1 – control	Control – only receive normal outreach / marketplace information from utilities, and normal newsletter from trash hauler. No difference in these materials from what all routes receive.
Route 2 – Partial Treatment	Received project-developed CBSM-type outreach materials
Route 3 – Full Treatment	Received same as Route 2 PLUS in-person / door-to-door and phone discussions on energy and recycling

Each route was given a slightly different treatment and results were measured pre, during, post, and a post-post to test for impacts including behavior retention. The outreach and education was designed to impact both waste diversion and energy efficiency (EE) actions and behaviors. Measurement of the impacts and costs of the outreach was conducted with multiple metrics, listed in Table 2 below.

Table 2: Data Collection / Measurements

Action	Description	Pre	During	Post	Post-Post[6]
Web-based surveys	Conducted pre and post. Measured attitudes, knowledge, behavior occurrence (energy & recycling), etc.; includes purchase of CFL bulbs, weatherization, car idling, recycling, attitudes, occupancy, and other information.	All		All	
Recycling Actions taken	The waste hauler provided weekly tonnage and participation reports for each route to support	All	All	All	All

[5] Another reason both recycling and energy initiatives were included was because the authors conducted work demonstrating the relative costs of achieving reductions in greenhouse gas including both recycling and energy measures. The work (SERA 2009) showed recycling programs were more cost-effective than many energy programs in reducing Metric Tons of Carbon Equivalent (MTCE). One ultimate goal of this project is to identify where in this cost-effectiveness spectrum, this CBSM project falls in its cost-effectiveness at achieving reductions in MTCE.

[6] For retention

Action	Description	Pre	During	Post	Post-Post[6]
	comparison of pre-post and test vs. control routes				
Set-out surveying	Selected random set of households to observe and weight trash and recycling to compute recycling rates and identify contamination and other issues.	All	All	All	All
Waste composition	Sorted a random sample of trash from each of the 3 routes to compare the relative amount (and type) of recyclables still in place in the trash.			All	
Web-site visits	Tracked hits & other data to measure interest in the project.		2 & 3		
Joining Club	Monitored number of households requesting to join the project's "Recycling Club" and Facebook™ sign-ups by route		2 & 3		
Verbal commitments	Collected during one-on-one visits.		Route 3		
Written commitments	Written commitments were collected either through the web site, or through return-mail postcards.		Route 2		
EE actions	Energy Efficiency Actions taken were measured using interviews and surveys	All	All	All	All

In preparation for the work, we conducted focus groups to gauge green interest, identify barriers and gather other background information for the project. As discussed below, these influenced the conduct of the project. Our rounds of interventions are described in the following table.

Table 3: Rounds of Intervention for the Control and Test Routes

Intervention	Route 1 (control)	Route 2 (partial)	Route 3 (full)
Up-front request for baseline survey – post-card (1st and 2nd mail)	Yes	Yes	Yes
Color handbills / pamphlets / door-hangers taped to trash / recycling cart (3 rounds, 3 different messages including both energy & recycling tips / goals / challenges)	No	Yes	Yes
Direct mail informational postcard outreach (1 round)	No	Yes	Yes
Commitment cards (mailed)	No	Yes	Yes
Commitment cards (in-person)	No	No	Yes
Door-to-door visits or door-hangers for those not home (2 rounds)	No	No	Yes
Reminder postcards about energy & recycling commitments households signed up for	No	Yes	Yes
Reminder emails about the energy & recycling commitments households signed up for (every 4-6 weeks if emails provided)	No	Yes, if email available	Yes, if email available
Bumper stickers available upon request for pasting on trash / recycling carts	No	Yes	Yes
Recycling contest, providing a prize for randomly selected household with no recycling in trash, and no trash in recycling	No	Yes	Yes
Phone calls announcing a "house tightening week" challenge / event[7]	No	Yes	Yes
Phone call reminder about recycling day	No	Yes	Yes
Postcard request for post-survey (1st and second mail)	Yes	Yes	Yes

[7] For this intervention, we told Route 3 we would call them back the following week to see if they had a chance to do the weatherstripping /caulking we suggested; for Route 2 we called back, but without the warning.

Intervention	Route 1 (control)	Route 2 (partial)	Route 3 (full)
Phone call post-surveys	Yes	Yes	Yes
Continuous monitoring of trash and recycling tonnages for 2 years[8]; also post-post survey planned.	Yes, not yet	Yes, not yet	Yes, not yet

A key deliverable for the project was a social marketing toolkit. The toolkit summarized key elements of the literature on CBSM, and identified lessons and gaps in the literature (especially costs). The toolkit was designed to provide a practical summary of the options, methods, lessons, and costs associated with key elements of CBSM programs, including goal setting, targeting, barriers analysis, intervention development, outreach methods and tools, and measurement. In addition, we included a computational tool to allow CBSM program planners to compute the cost of self-selected research and outreach steps, to help plan for a program that will avoid exceeding budget and staffing limits.

Baseline, Prompts, Feedback

Baseline measurement was necessary to measure incremental impacts attributable to the project's interventions, and these impacts were essential to computing the relative costs-per-impact for the two test routes. Different methods were used to establish the trash/recycling and energy baselines.

- *Trash and recycling baseline:* A baseline of set-outs, trash collection, recycling collection, participation, diversion rates, and subscription levels was established as a starting point for before, during, and after project comparison. The local hauler provided tonnages for trash and recycling weekly (along with the number of homes NOT recycling each week), and SERA's set out surveys gathered data on household participation in the program (measured through whether or not recycling bins were set-out at the curb), contamination in the recycling (a measure of knowledge of recycling practices), and trash and recycling generation on a household-by-household basis.
- *Energy Baseline:* Collecting metered data on energy use for the routes was not possible for the project. Instead, proxies for energy behavior were established and collected through surveying, focus groups, and one-on-one household visits. The authors used metrics such as reported average monthly energy bills (for pre/post comparisons) the number of CFLs in each house, the frequency / likelihood that respondents undertook energy efficient behaviors such as purchasing ENERGY STAR® appliances, reduced automobile idling time, used low-flow shower heads or limited shower times, and others. We also gathered information on energy knowledge items, which we compared between routes and as pre/post comparisons.

Baseline Survey, interviews and focus groups: <u>*Survey:*</u> Nearly 170 pre-treatment survey responses were collected from the three routes.[9] The survey was used to identify the decision-makers in the household, the barriers to certain behaviors, the perceptions about energy and recycling, motivations, and general attitudes toward recycling and environmental issues. The results of the survey were also used to design specific outreach materials. Beyond the usual responses about behaviors, the survey uncovered additional information affecting the design of the project, including:

- Over 60% of respondents used Facebook – even for residents older than 35 - signaling to the researchers that establishing an on-line community would be a useful tool throughout the project.
- There was a rather low feeling of self-efficacy within the studied routes. Previous research by SERA has shown a high correlation between ratings of self-efficacy and the likelihood that participants will undertake an action (SERA 2006) and continue to do so. The survey uncovered such data as 30% of the households surveyed in the test routes reported that they *strongly agreed* with the statement that: "*What I do only makes a difference if others do it too*". This was used to help guide the marketing message. Outreach materials were designed to increase the feeling of self-efficacy among the target routes.

[8] As indicator of retention of all behaviors undertaken (if our research indicates it is a good indictor behavior).
[9] The response rates provide accuracy of about +/- 12% at 95% confidence, or about +/-10% at 90% confidence for each of the routes.

- Energy information such as average monthly energy bills, number of programmable thermostats and whether households were using the thermostats, walking/riding bikes to school, and others.

Interviews: The authors conducted brief interviews with relevant stakeholders in the host city regarding existing programs and outreach. These interviews were used to provide a different perspective on City issues, barriers, and to identify opportunities for increasing "green behaviors" and for leveraging with City events, HOA newsletters, and similar mechanisms for reaching residents.

Focus Group- We conducted evening focus groups with neighborhood residents in the assigned routes. The focus groups provided additional opportunities to learn as much background material about the project area to help guide the design of the outreach material. Beyond the responses in the survey, the focus groups provided the authors with input such as:

- We gathered advice / feedback on attractive names for the program, including words with the ability to elicit positive behavioral changes, etc. For example, "jobs", "economy", and "climate change" didn't work; preferred words were "easy", "habit forming", "natural resources", "smart", "natural", "future", "benefits", conscientious", "simple", "convenient", "responsible" and others.
- Residents do not see a strong link between recycling/diversion actions and impacts on greenhouse gas emissions or job creation. Trying to "sell" recycling as a way to reduce GHG impacts would not be an effective message. Strong, resonating motivators centered on saving resources and future generations.
- Public recognition for participation should be an important aspect of the outreach. Participants reported that they might do behaviors but their neighbors are not aware that they do so. This implies that visible labels like big star stickers on recycling cans, or labels that say "I compost too" or similar messages will help send positive messages and motivate behavior change.

Identify Barriers: One of the main goals of the surveys, interviews, and focus groups was to identify specific barriers to energy and recycling behaviors in the test and control neighborhoods. Prior to the delivery of any outreach materials, the barriers were identified and ways to overcome the barriers were developed and marketed in the outreach campaign.

Table 4: Energy and Recycling Barriers in the Test Neighborhood

Recycling Barriers	Energy Barriers
• Unaware of what materials can/can't be recycled • Not sure that collected materials are actually being recycled • Lack of self-efficacy • Lack of room to store recyclables/carts	• Not sure what actions to take • Cost • Lack of self-efficacy • Challenges in undertaking the behavior

Website: Along with a Facebook™ page for the project, an interactive website was used to incorporate a number of unique social marketing tools and best practices. Some of the web-based tools we developed for the project included:

1) *Commitment form*- a dedicated page allowing residents to sign commitment forms to the project. The commitments were made public (via the website and newsletters) and incentives were used (entry into a drawing to win $25 and $50 gift certificates to local stores) to help generate greater amounts of commitments.
2) *Prompts*- The website acted as a prompt in multiple ways including serving as a visual reminder to anyone who visits the site and sending out emails prompting households who made commitments to recycle
3) *Interactive map*- The website used a map of the routes/blocks in the neighborhood and allowed anyone logging on to roll over the map and see participation rates, (establishing norms) and diversion rates (feedback on the project)
4) *Develop an on-line community*- The website used links to social sites such as MySpace and Facebook to create an on-line community. In addition to helping spread the outreach materials and message, these tools were used to help establish norms in the community and routes.

Commitments: The project used multiple public commitments to promote the outreach campaign. As the case studies have shown, commitments, especially public ones, have repeatedly proven to be a powerful tool in shaping social behaviors. The project created a "Neighborhood Action Club" and Route 3 residents were given the opportunity to commit verbally and in writing to be members of the club. During door-to-door visits residents were asked to commit to:

- Recycling more cardboard, paperboard, and paper
- Installing at least 1 CFL
- Using power strips to turn off computers and electronics
- Recycle 7 more pounds per week to reach goals
- Join the challenge on the website

The challenges rotated, and included actions like talking to one neighbor about ways to increase energy efficiency and recycling in the house; turning off the car if idling will exceed 30 seconds; and a number of other challenges. Membership in BAC was made public through the web-site and neighborhood newsletters. Tools to make the commitments ***public*** (an important part of social marketing) included: Stickers on trash cans, window decals; HOA Newsletter; project website, and other means.

Prompts: A number of the earlier measures described were designed to serve as *prompts* in the CBSM campaign. The website (for those that log on to it) was a visual prompt and any test route residents whose email was obtained through the on-line survey or door to door visits was sent periodic email reminders to undertake certain conservation behaviors. We also used stickers / decals and magnets that residents were able to put on their refrigerators to remind them about actions they could take. A key prompt throughout the project was the use of colorful, printed informational materials taped to the recycling carts. These "cart hangers" functioned as both a prompt for the desired behavior and as a feedback mechanism for program progress.[10]

Feedback: The door-hanger prompts also functioned as a feedback mechanism for participants. The pre-treatment survey uncovered that residents were unaware of current diversion rates and were interested in learning what impacts the EE actions they were taking had. In addition to the door-hangers, the project used the website for feedback. The feedback allowed residents to assess progress toward the stated goals and used bright graphics, and relatable statistics (i.e. cars of the road, trees saved, etc.) to engage participant interest. We provided information on colorful "facts" about recycling and energy (See Figure 1 for example). The hangers let residents know how many people had taken the My Green Neighborhood challenge, the pounds of CO2 reduced to date, the increases in the recycling rate, and the overall number of actions taken in the neighborhood. **Reminders:** The residents that joined the My Green Neighborhood Challenge (made a commitment) were sent a reminder of their commitments along with updates on the number of households taking the challenge, the impacts of the project to date, and an "ask" for additional commitments to green actions.

Home Visits and Phone Calls: The difference between Route 2 and 3 was the home visits. We hired teens to accompany adults (and in some cases, two adults) to conduct the home visits on Route 3.[11] The home visits incorporated a number of social marketing tools and tips into the home visits to make them as effective as possible. The door-to-door volunteers asked households to make a verbal commitment to undertake actions. If the residents agreed to a verbal commitment, they were then asked to make a written commitment, by filling out and signing the same postcard used for Route 2. This in-person commitment request distinguishes route 2 (written request for commitment) from the higher social marketing efforts of route 3. At the suggestion of the literature, we also used multiple senses. While some residents were more receptive to a verbal message, others seemed to be more receptive to a tactile

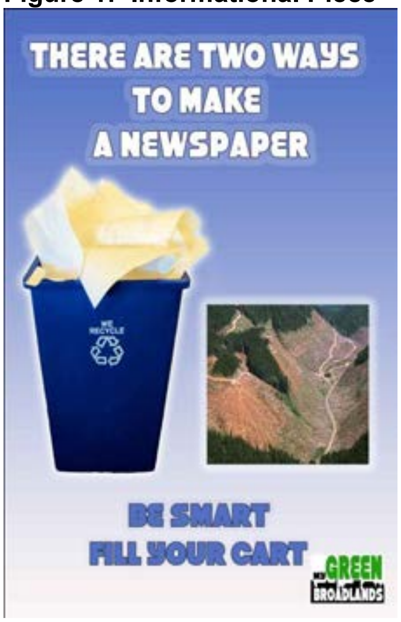
[10] A previously conducted door hanger campaign from Laverne, CA found that residents receiving feedback/prompts recycled 19% more than the control route (Aceti, et.al. 2003).

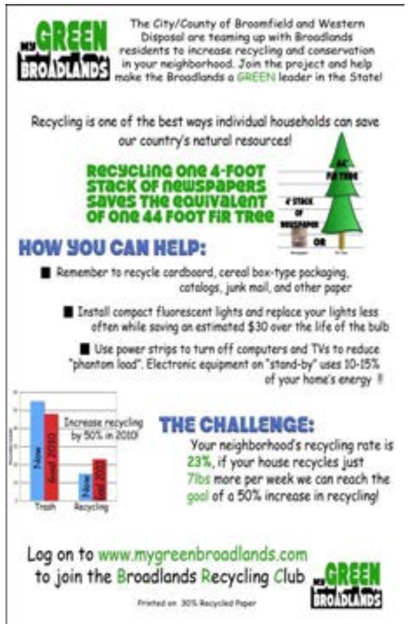
[11] Our review of the social marketing literature indicated that having young persons involved in conducting the door-to-door work made residents more willing to open their doors to the teams. We found this seemed to work well in the field..

message. The volunteers were provided with examples of recycled items and CFLs to let residents touch and feel to help get the message across.

We purchased phone numbers for the addresses (about 50% of the addresses were able to be “matched” with phone numbers), and called households in both Routes 2 and 3. We first announced a “home seal/up / weatherstripping” event, asking households, referring them to instructions on the website and asking them to take simple measures seal their homes. Route 3 was told they’d be called back the following week; we called both groups back about 2 weeks later. We also called the homes to remind them about recycling day on one occasion to check for changes in recycling participation.

Figure 1: Informational Piece – Sample





Recognition, rewards, and incentives: For both Routes 2 and 3, households that committed to recycle or take other energy behaviors were recognized through website and decals. We also ran a “Random Recycling Award” program for one month (four collections). If a randomly selected house[12] had no recycling in the trash and no trash in the recycling they won a gift certificate and were publicly recognized as the months “outstanding recycler”. <u>Incentive</u>: As an added incentive to get residents to make the public commitment (post their names up on the website) we offered to donate $1 to a local non-profit in their name if they make the public commitment.

Results and Comparisons – Performance of CBSM

Combined, these social marketing tools were incorporated to increase energy efficient behaviors and recycling participation and rates in the Broomfield neighborhood. The remainder of this paper summarizes the impacts of the various outreach efforts and the relative costs per impact for the CBSM outreach.

Committed Activities would save 360 MTCO2E per Year: In the two test routes 12.5% of all households made the commitment to undertake energy saving and recycling actions. When residents took the commitments they were asked whether they were committing individually or for their entire household. When all household members are included, more than 500 people committed to taking green actions. Overall, there were 2,300 committed green actions. Assuming these actions were undertaken,

[12] We knocked on the door and asked permission before sorting their trash and recycling, of course! Each week of the contest, we generated a list of 10 random households to check.

their GHG reductions could total more than 720,000 pounds of GHG emissions were avoided in a year[13]. Table 5 below displays the distribution of the committed actions. The least popular action was *"Talk to a neighbor about energy efficiency or recycling"* and the most popular energy action was *"Install one CFL".*

Table 5: Household Committed Green Actions (n=214)

Install 1 CFL	Use power strip to turn off electronics	Turn off car when idling	Use cold water for laundry	Talk to one neighbor	7 pounds more recycling	Recycle all paper and OCC	Use 1 re-useable bag when shopping
69.6%	34.4%	56.0%	68.8%	28.0%	52.8%	83.2%	63.2%

Many More Commitments in Route 3: The vast majority of the commitments were the result of the door-to-door outreach in Route 3. In Route 2 only 1% of all households committed to joining the challenge; in Route 3, the full outreach route, 24.6% of the households joined the challenge and committed to taking green actions. About 15% of the total commitments were made using the on-line commitment form while 85% were made in person using the commitment cards. Only 11% of the committed residents opted out of the public commitment while 89% made public commitments and had their names published on the website.

Full Treatment Route 3 Had Bigger – and More Persistent - Recycling Increase: Recycling was easily monitored every week (it is visible and on-the-street); thus, it was considered a key indicator of the program's effect. All three routes saw an increase in recycling; however the two target routes saw the largest increases. Figure 2 shows the change in recycling tons per household for all three routes from the "pre" period compared to the end of outreach, and compared to the period 6 months after the last outreach. All three routes saw an increase in recycling; however in the "post" period, Routes 2 and 3 increased by 1.8 and 3.2 times as much as the control route, respectively. After 6 months, Route 3's increase had maintained, but Route 2 had drifted back toward the control group. We will continue to monitor this effect for at least one more year.

Based on the impacts and data collected throughout the project, although it costs significantly more (almost six times more expensive in our project) to conduct door to door outreach, the impacts are also significantly higher. The vast majority of GHG savings, commitments, and the largest increases in recycling occurred in the Route 3. We computed the relative cost per commitment, per ton, and per metric ton of CO2e and found: the cost per commitment in Route 3 was 18% of the cost for Route 2; per ton recycled, the cost as 67% as high, and the cost per MTCO2e (based on commitments) was 23% as high in Route 3 as Route 2. The data were also used to compute the cost per MTCE reduced (based on impacts on recycled tons), and this information is presented, in context, in Figure 3.

[13] This estimate was for lbs of CO_2e from January 2010 through December 2010, and are computed assuming they last one year.

Figure 2: Percent increase in Recycling per Household

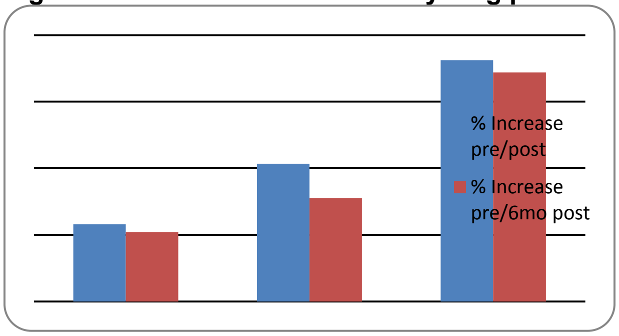
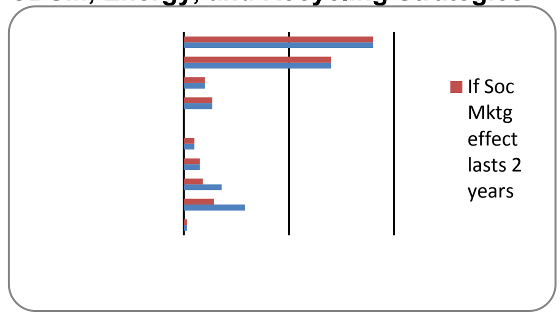


Figure 3: Relative Cost per MTCE for CBSM, Energy, and Recycling Strategies[14]



Energy Knowledge and Behaviors Improved More in Route 3: Although differences in energy knowledge and behaviors could only be monitored by self-report surveys, the results also showed greater effects in Route 3 than in Route 2. Results for a number of the energy-related behaviors follow in Table 6.

Table 6. Energy Behavior Responses

	Route 1 (control)	Route 2 (partial treatment)	Route 3 (full treatment)
Number of last 2 loads of laundry that were rinsed in cold	n/a	1.48	1.76 (19% more than low treatment group)
Turned off power strip yesterday (% yes)	11.3%	17.6% (56% more than control group)	20.5% (81% more than control)
Adjusted thermostat up one degree in summer and/or down one degree in winter (% yes)	41.9%	54.5% (30% more than control)	55.3% (32% more than control)
Installed caulking in the last year (% yes)	n/a	11.8%	36.8% (312% more than low treatment group)

Summary and Conclusions

Decades of literature claims community based social marketing programs can be very effective. Social marketing, with its personal, tailored approach, addressing of "barriers" and ample use of targeted outreach potentially show promise for cutting through the millions of messages that households see every day. This project sought to test that claim by monitoring changes in recycling and energy behaviors, but especially to fill two gaps in the literature – persistence of the impacts and behavior changes, and the resulting cost-effectiveness of the interventions. We found that full social marketing (with door-to-door components) can deliver very strong energy (and recycling) behavior changes, and even though it cost more to visit each household, the impacts were so much higher that the cost-per-impact from these interventions is considerably lower than found in the partial test route.

The initial results on retention show that full social marketing efforts, with a "personal" touch, seem to lead to much better retention of the behavior change. Although six months may only be an indicative follow-up so far, the fall-off in behaviors for the full CBSM outreach is so much lower than the control or partial test routes that – if we make an assumption that the behaviors may last two years - the cost-effectiveness of achieving a reduction in one Metric Ton of Carbon Equivalent from a full CBSM program may be on par with traditional commercial and residential energy efficiency programs (and only a bit more than recycling and composting collection programs).

[14] Costs for the recycling and energy strategies are from Skumatz 2009. Abbreviations follow: Comm'l EE – commercial energy efficiency program, specifically commercial lighting; Res Weath – (typical) residential weatherization program; C/S recy – Curbside recycling program; C/W YW – curbside yard waste program; PAYT – Pay As You Throw trash rates, with higher bills for bigger cans to provide recycling and diversion incentive.

Follow-up work on the project will examine whether the impacts do, in fact, last the full two years – or perhaps even longer! The project has helped rank CBSM costs relative to other energy and recycling strategies, and retention work looks promising, based on “indicator” behaviors. The results indicate the costs and retention from CBSM is favorable – and “the bang may in fact be worth the buck!”

References

Aceti, Jen, Doug Mckenzie-Mohr, and David Hirschler. 2003. “Using Normative Feedback to Increase Recycling Participation in the Town of Dedham”, prepared for the Massachusetts Department of Environmental Protection.

Andreasen, Alan, 1995. Marketing Social Change: Changing Behavior to Promote Health, Social Development, and the Environment. Washington, D.C.:HB Printing.

Andreasen, Alan. 2000. Social Marketing in the 21st Century. Thousand Oaks, CA: Sage Publishing.

Hjelmar, Ulf, 2005. The Concept of Commitment as a Basis for Social Marketing Efforts: Conversion Model as a Case, *Social Marketing Quarterly*, 1539-4093, Volume 11, Issue 2, 2005, Pages 58 – 63

Kotler, Phillip and Nancy Lee. 2008. Social Marketing, Influencing Behaviors for Good, Third Edition. Thousand Oaks, CA: Sage Publishing.

McKenzie-Mohr, Doug. 1999. Fostering Sustainable Behavior: An Introduction to Community-Based Social Marketing. British Columbia: New Society Publishers.

Skumatz Economic Research Associates, Inc. 2006. “Alliance to Save Energy’s Green Campus Program, Year 1 & 2 Evaluation Report”, Prepared for California Public Utilities Commission, San Francisco, CA.

Skumatz, Lisa A., Ph.D., 2009. “Do Energy Efficiency Strategies Outperform Recycling in GHG Mitigation and Job Creation?”, proceedings of the IEPEC conference, Portland, OR.

Skumatz, Lisa and John Green. 2000. “Evaluating the Impacts of Education/Outreach Programs – Lessons on Impacts, Methods, and Optimal Education”. Proceedings from ACEEE Conference, Asilomar, CA.

Skumatz, Lisa A., Carol Mulholland, and Sharyn Barata, 2009, “Social Marketing: Evaluating the Social Twist on Marketing Programs”, AESP Strategies Article, Association of Energy Services Professionals, Spring 2009

Simulation of the Italian Domestic Household's Daily Load Shape through a Psychological Model of Demand: Application to Standby Power Demand.

Alberto Prudenzi, Andrea Silvestri*, Regina Lamedica**, Maria Carmen Falvo**, Massimo Regoli****

University of L'Aquila, Italy, **University of Rome Sapienza, Italy, * 2nd University of Rome "Tor Vergata", Italy.*

Abstract

The paper aims at illustrating the validation activity of a residential electric load simulator that implements a psychological model of the customer's energy usage to simulate daily load shapes obtained by means of a bottom-up mechanism based upon interaction between household's members and individual appliances. In the paper, some main figures of the simulation model are reported in due detail and some main results of the validation activity performed on the model as applied to available data relevant to the Italian household are reported and commented. Finally, in order to provide an example of the load simulator possible use, the standby power daily load pattern of an average Italian household has been analysed and the possible impact on daily load shape of various load management strategies has been simulated.

Introduction

The development of models for ascertaining the load shape in residential end-use areas is a cost-effective option for electric companies as it allows reduction of load investigations to the ones only required for model tuning and validation, thus allowing ex-ante evaluations of energy and demand management programs.

A model of the residential customer's demand has been proposed in the recent past called DELOS (Domestic Electrical LOad Simulator) that acts as a residential customer's load simulator [1]. The model is aimed at simulating the daily electric load shape of a residential area by aggregating individual households' daily load profiles. Every individual household's daily load profile, on its turn, is given by aggregation of individual electric appliances load pattern. Thus the model provides a constructive approach by following a bottom-up mechanism that is basically based upon interaction between the household's member and the single appliance being part of household's typical mix [2]. The bottom-up approach of the model takes origin from the model in [16]. This approach is in common with further models such as those in [17,18].

Thus, both data obtained from load research activities and data concerning people lifestyle, household's typical appliance mix and pattern-of-use, as well as energy and demand typical figures, must be input in the model for simulating daily load shapes of domestic end-users.

A validation activity has been then assessed by comparing electrical daily load diagrams made available by load research activities (Eureco, Remodece) with diagrams obtained from simulations [4]. To this aim a wide research activity has been performed in order to apply the model to the simulation of an average Italian domestic customer. The results thus obtained are promising since they show the possibility of providing meaningful indicators concerning residential customers' daily load shape by starting from socio-economic and demographic data typically being easily available from National statistics.

Finally, the load simulator thus validated has been applied to a case study in order to give an example of model utility in determining typical pattern-of-use of standby operating modes that are strictly linked to lifestyle concepts and rules. In particular the model has been used to firstly identify typical daily load pattern of standby power overall demand and, then, to parametrically simulate some more diffuse demand management strategies in order to predict possible impacts of standby power demand reduction on the average household's daily load shape.

The Load Simulator

The available load simulator reproduces the daily electric load shape of a residential area by aggregating contributions of individual households. The individual household's daily load shape, on its turn, is the result of the elemental contributions of electric appliances demand being part of his typical mix. Thus the program provides a constructive approach to the load shaping problem by following a bottom-up mechanism based upon interaction between the household's member and individual appliance [19, 20]. The program output provides, besides the daily load shape of the investigated area, a series of partial figures relevant to every different level of aggregation that can be of a certain utility for the investigation, such as:

- the average daily pattern-of-use of individual appliance types,
- the average daily load shape for individual household and household member types,
- the average daily availability-at-home patterns for each household member types,
- and many others.

For that concerns Italian domestic customer and domestic electric energy usage in general, the data required for simulation are typically found in periodical research reports made available by institutional sources (ISTAT, CENSIS, etc.). Demographic and socio economic studies periodically produced for the Country are typically basic sources of data required by household's model in the programme. Such data are generally obtained from "time-use" or "multi-purpose" surveys performed on households [3].The input data for DELOS are obtained from the above mentioned surveys.

Simulation of Italian Household's Daily Load Shape

The model has been applied to the Italian residential scenario in order to reproduce typical daily load shapes through a bottom-up approach [1]. Data deriving from both National statistics and specific surveys have been used in order to simulate an average Italian domestic customer's daily load shape for different day types and different types of demographic areas. The simulation results have been compared with results found valid for Italy from two well known European research programs (Remodece and Eureco) [5,6]. Fig. 1 shows the comparison between DELOS simulation results (average for a week day) and some results from both Remodece (RD) and Eureco (ED) research programs. The figure shows a substantial agreement of simulation results with monitoring results.

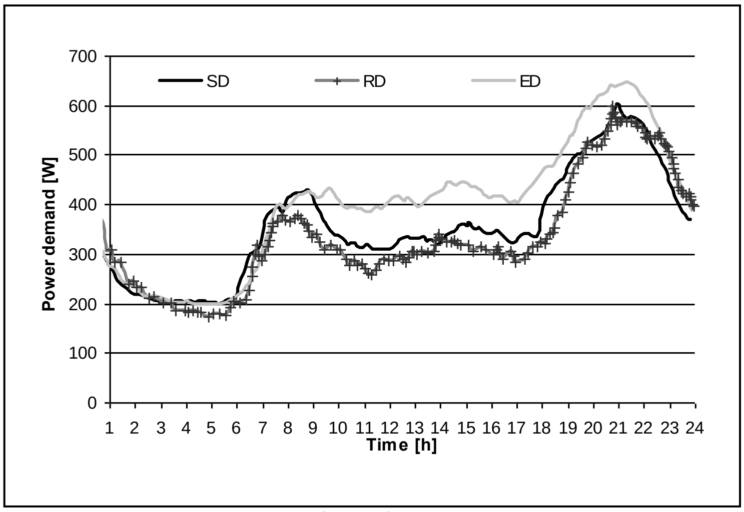


Figure 1 Daily load profiles for comparison evaluation among DELOS simulation (SD) and both Remodece (RD) and Eureco (ED) experimental results.

TABLE I Numerical figures of the daily load profiles in Fig. 1

	Daily Energy [kWh]	P_{max1} [W] morning time	P_{max2} [W] evening time
Sim.	8.4	426	601
Meas. 1	8	379	600
Meas. 2	9.4	430	645

In Table I the comparison among simulation and measurement results is reported in detail. In particular, daily energy consumptions and daily load peaks of the different diagrams are compared. The comparison has been also extended to individual appliance daily load shapes. The extensive comparison thus performed shows the good results of both validation and calibration activities of the simulation model. In Figs. 2-4, the daily load profiles obtained from simulation and the measurement campaigns results are compared for three typical appliance classes in order to give an example of the validation activity. The figures show a good agreement of simulations with measurement results. A generally better agreement with Remodece results could be explained with the fact that such a campaign is more recent. In Tables II-IV the comparison has been evaluated in terms of energy consumption and reported.

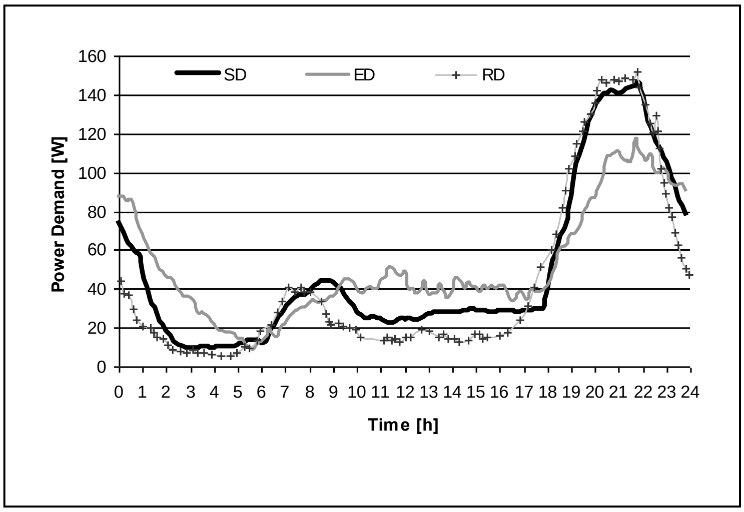


Figure 2 Daily load profiles for comparison evaluation (lighting usage for working day)

TABLE II Comparison of energy consumption values in Fig. 2

	ED [kWh]	SD [kWh]	RD [kWh]
Daily Energy	1.22	1.17	1.02

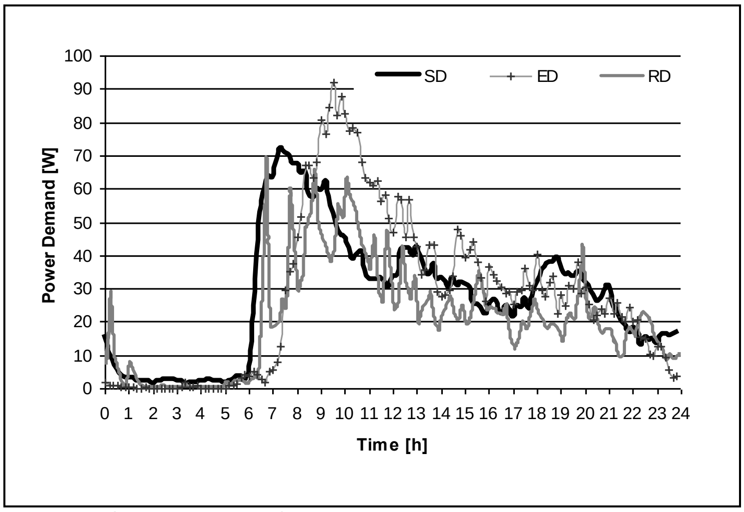


Figure 3 Comparison for washing machine working day daily load shapes

TABLE III Comparison of energy consumption values in Fig. 3

	ED[kWh]	SD [kWh]	RD [kWh]
Daily Energy	0.67	0.66	0.62

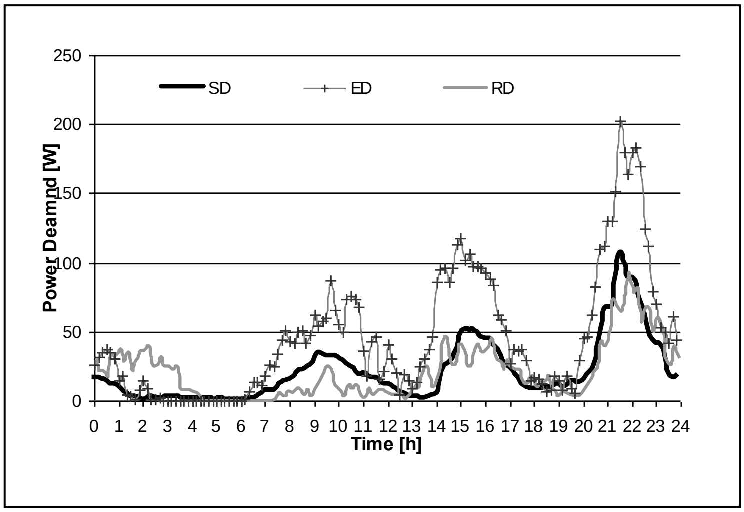


Figure 4 Comparison for dish washer working day daily load shape

TABLE IV Comparison of energy consumption values in Fig. 4

	E.D.[kWh]	S.D. [kWh]	R.D.[kWh]
Daily Energy	1.1	0.51	0.51

Analysis of Standby Power

After having duely validated the model, it has been extensively applied in a study focused on the analysis of residential standby power demand. As it is well known, standby power is generally defined as the electricity consumed by end-use electrical equipment when it is switched off or not performing its main function. The most common users of standby power are televisions (TVs) and video equipment with remote controls, electrical equipment with external low-voltage power supplies (e.g., cordless telephones), office equipment, and devices with continuous digital displays (e.g., microwave ovens) [7]. Although consumption by individual appliances is small, the cumulative total is significant. Indeed, standby energy is currently estimated as one of the largest individual electrical end uses in the residential sector with a total impact nearly equivalent to the energy consumption of refrigerators and freezers in many developed countries [8]. International studies based on experimental campaigns performed at households have indicated [9,10]:

1) a standby power demand per household in the range 33-125 W;

2) a standby annual energy consumption in the range 277-1,100 kWh/year;

3) a standby use range from 3 to 14 percent of residential electricity use, depending on the country and the specific measurement procedures used in the surveys.

The global energy consumption from standby has been estimated by the International Energy Agency (IEA) at between 200 TWh and 400 TWh per year [11]. The amount of standby energy varies markedly between countries. This in part is due to the different penetration of appliances but also to differences in their standby attributes. Indeed, the energy consumption in low power modes is highly variable at a product level and in some cases is highly dependent on consumer pattern-of-use. Among consumer electronics, the most common appliances characterized by a standby mode of operation, it is possible to include the following:

- the TV class that has the highest standby power consumption due to the remote control and instant-on features, memory, and clock displays.
- Audio and Hi-Fi equipment with about 70% of their energy consumption due to standby mode.
- Set-top boxes including all units that are used in combination with the television set (cable boxes, satellite receivers, Internet appliances and video game units).
- Battery-charging devices like cell phones, personal stereos, electric shavers, toothbrushes, etc.. These devices have standby modes due to typical lack of off switch. Moreover, some battery chargers do not reduce the current once the battery is fully charged.
- Small kitchen appliances such as blenders, bread makers, rice cookers and toasters that are typically available with soft touch controls, microprocessors and displays.
- PCs, external modems, phone/fax/copier combos, and scanners that are currently very common in the residential sector.
- Cordless phones, and phones with answering machines, each equipped with its own power cord and AC/DC adapter.

The standby power of individual appliances to be simulated has been obtained from literature data sets [12,13]. In particular, from such data both power demand and typical duration variability ranges have been taken for each appliance or appliance class as typically characterized by stand by operation mode. For each simulated appliance or class the actual values in each simulation are determined through a Montecarlo process applied to the considered range.

After having successfully performed an in-depth calibration activity of the model on the literature data [4], the load simulator can be considered as a valid model for effectively reproducing the customer's electric energy pattern-of-use in the investigated area. Starting from the knowledge of the average daily pattern-of-use of individual appliance types, DELOS has been used to simulate the standby power demand daily profile of the average Italian household. The relevant result is reported in Fig. 1. Therefore, the standby power impact both on energy consumption and on daily demand of Italian domestic customer has been estimated. In Table V both daily energy consumption and power demand values at peak hours are evidenced. The standby daily energy consumption has been obtained as about 11% of the total daily energy consumption and its contribution at typical working day daily peaks is in the range of 7- 10%.

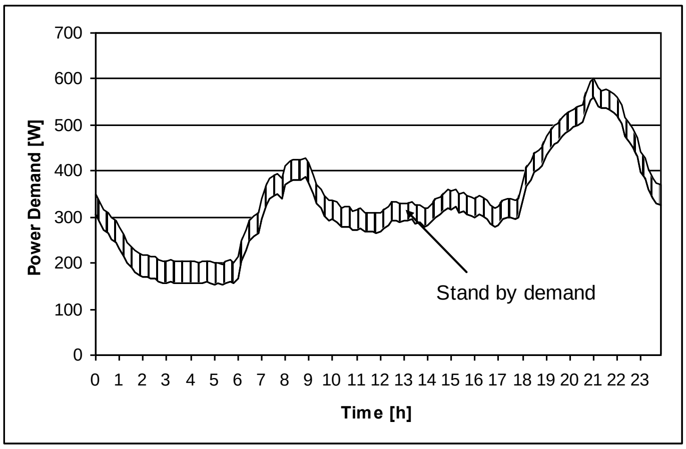


Figure 5 Standby power contribution to the daily load shape for an Italian average household

TABLE V Numerical figures of the daily load profile in Fig. 5

	daily energy [kWh]	P_{max1} [W] morning peak	P_{max2} [W] evening peak
Total demand	8.4	429	601
Standby demand	1.1	46	42

The numerical figures of the daily load shape of the standby power as obtained from the simulation stage are reported in Table VI. A range of variation of the daily demand profile up to 18% has been found. This evidences the fact that even standby power demand should be better analyzed in terms of domestic appliances typical time of usage.

TABLE VI

	P_{avg} [W]	P_{min} [W]	P_{max} [W]
Standby total demand	43	39	48

Prediction of Standby Load Management Impact

In countries having an energy efficiency policy, standby power currently plays an important role. Although policy instruments much vary with countries [14].

The technological improvements that are typically recognized in this field are included in the two tiered approaches such as the NRCan regulation's or EC standard's ones [14,15] .

The bottom up approach implemented in DELOS model easily allows simulation of such technological improvements adopted in domestic appliances characterized by standby power mode in order to reduce demand. So, the two following scenarios have been simulated:

- NRC T1 providing appliance respecting limits similar to NRCan regulation Tier 1.
- EU T1 providing appliance respecting limits similar to European standard's Tier 1.

In Table VII the above mentioned limits are reported in detail. For each scenario, different penetration levels have been considered, respectively of 100, 30 and 60%. The standby daily load shapes thus simulated have been compared with the actual daily load shape of Fig 1. The comparison is reported in Figs. 6-8. The comparison is also reported in numerical detail in Tables VIII – X.

TABLE VII Standby demand limits for the two standard scenarios

Product Type	Tier 1 NRCan	Tier 1 Europe
Compact Audio	3W	1W
Televisions	4W	1W
Video Equipment	3W	1W

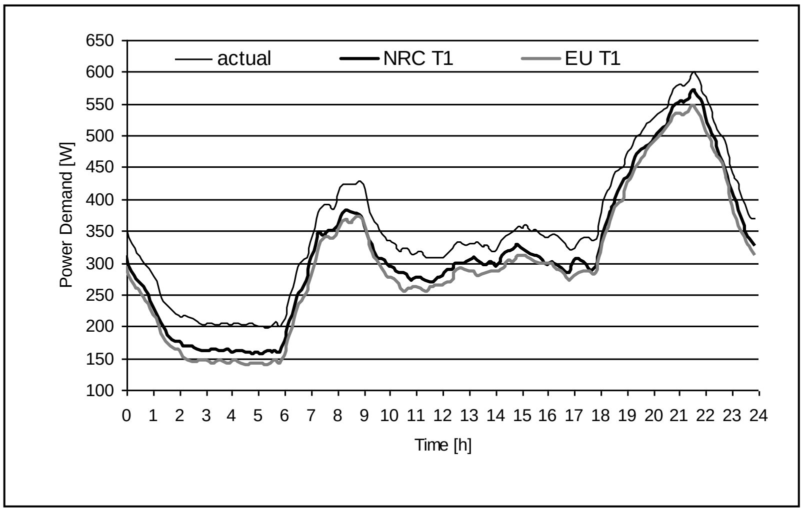


Figure 6 Load shape impact for 100 % penetration

TABLE VIII Numerical figures of the daily load profiles in Fig. 6

	daily energy [kWh]	P_{max1} [W] morning time	P_{max2} [W] evening time
EU T1	7.53	372	548
NRC T1	7.18	383	572

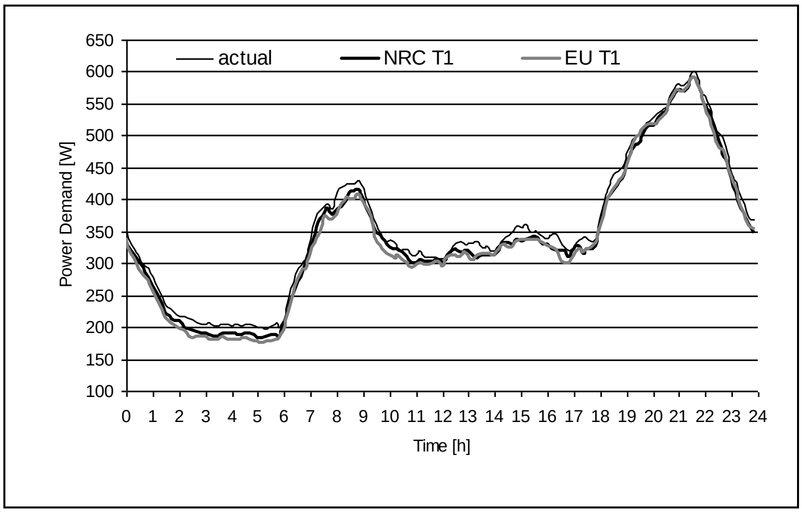


Figure 7 Load shape impact for 30 % penetration

TABLE IX Numerical figures of the daily load profile in Fig. 7

	daily energy [kWh]	P_{max1} [W] morning time	P_{max2} [W] evening time
EU T1	8	407	590
NRC T1	8.13	416	592

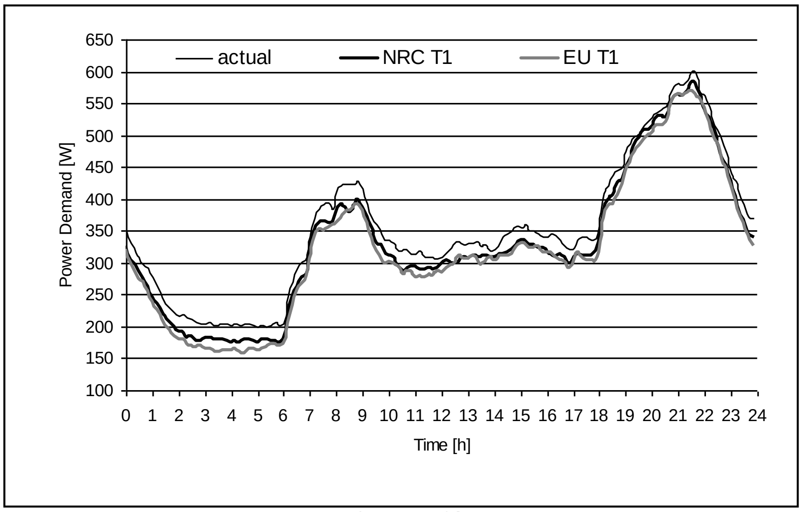


Figure 8 Load shape impact for 60 % penetration

TABLE X Numerical figures of the daily load profile in Fig. 8

	daily energy [kWh]	**P_{max1} [W]** morning time	**P_{max2} [W]** evening time
EU T1	7.71	392	570
NRC T1	7.91	400	584

Conclusions

A domestic load simulator implementing a bottom-up approach based on a psychological model of household's energy usage has been applied to the simulation of an average Italian household's daily load shape. Data typically available from Statistical National Institution have been used for simulation. In order to validate simulation results, a comparison has been evaluated in due detail with results of experimental campaigns for the Italian households as made available from two well known European research projects. Finally, the possible impact of standby demand management strategies with increasing penetrations at customers' has been predicted on the average household's daily load shape. The simulation results that can be obtained, since providing, in parametrical terms, the anticipation of effects of some demand management actions prior to actual implementation or experimentation, can be usefully adopted by electricity distributors for assessing the technical-economical evaluations that are typically the very preliminary step toward demand management actions implementation.

References

[1] Prudenzi A., Silvestri A., Regoli M. *A Residential Electric Load Simulator to Support Demand Management Strategies in Competitive Electricity Markets.* Proc. of the 5th International Conference on Energy Effciency in Domestic Appliances and Lighting (EEDAL'09), 2009

[2] Capasso A., Grattieri W., Lamedica R., Prudenzi A. *A bottom-up approach to residential load modeling.* IEEE Trans. on Power Systems, Vol. 9, No. 2, pp. 957-964, 1994.

[3] Romano M.C. *Time use in daily life, A multidisciplinary approach to the Time use's analysis.* Tech. Rep. ISTAT no 35, 2008.

[4] Prudenzi A., Silvestri A., Lamedica R., Falvo M.C. , Regoli M. *A domestic electric load simulator including psychological aspects of demand*. Proc. of IEEE-PES 2010 General Meeting, Minneapolis, USA, July 25 - 29, 2010.

[5] De Almeida A., Fonseca P. *Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe.* Proc. of Eceee 2007 Summer Study,2007.

[6] Sidler O. *EURECO: End-use metering campaign in 400 households of the European Community Assessment of the Potential Electricity Savings*. 2002 .

[7] Mohanty B. *Standby power losses in household electrical appliance and office eq*uipment. Presented at the regional Symposium on Energy Efficiency Standards and Labeling, from 29 to 31 May 2001

[8] Brown R., Rittelman W., Parker D., Homan G. *Appliances, Lighting, Electronics, and Miscellaneous Equipment Electricity Use in New Homes.* Proc. of ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove,2006

[9] Meier A. *A worldwide review of standby power use in homes*. Tech. Rep. Lawrence Berkeley National Laboratory, Dec. 2001

[10] P. Bertoldi P., Aebischer B., Edlington C., Hershberg C., Lebot B., Lin J., Marker T., Meier A., Nakagami H., Shibata Y., Siderius H., Webber C. *Standby power use: How big is the problem? What policies and technical solutions can address it?* Proc. of the Summer Conference of the American Council for an Energy-Efficient Economy ,Washington ,DC , 2003

[11] E3, *Order out of Chaos*. Summary paper for the international standby power conference, Canberra, Australia, 6-7 November 2006. Paper available from www.energyrating.gov.au under E3 events.

[12] Da Silva D., Rivière P., Cho Y., Adnot J.*Consumption monitoring campaign of standby and off-mode energy losses in new equipments*. Tech. Rep. SELINA project, 2010. Available: http://www.selina-project.eu

[13] Fraunhofer IZM: *EuP Preparatory Studies "Standby and off-mode losses*"(TREN/Lot 6), Final Report, October 2007. Available: http://www.ecostandby.org

[14] Harrington L., Hans-Paul Siderius, Novem S., Ellis M. S*tandby Power: building a coherent international policy framework*. Presented at ACEEE Summer Study 2008, California

[15] http://oee.nrcan.gc.ca/regulations/proposed.cfm

[16] Walker C. F., Pokoski J. L., Residential load shape modeling based on customer behavior", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104, n. 7, 1985.

[17] Richardson I., Thomson M., Infield D., Clifford C., Domestic Electricity Use: A High-Resolution Energy Demand Model, Energy and Buildings, Elsevier, Volume 42, Issue 10, pp. 1878-1887, October 2010.

[18] Pateero J., Lund P., A model for generating household electricity load profiles, International Journal of Energy Research, Elsevier, Volume 30, Issue 5, pp. 273-290, 2006.

[19] Capasso A., Grattieri W., Invernizzi A., Insinga F., Lamedica R., Prudenzi A., Validation tests and applications of a model for Demand-Side Management studies in residential load areas Proc. CIRED 1993, 12-th International Conference on Electricity Distribution, Birmingham, 17-21 May, 1993.

[20] Capasso A., Lamedica R., Prudenzi A., Probabilistic processing of survey collected data in a residential load area for hourly demand profile estimation, Proc. IEEE APT'93 Technical Conference, 3-6 Sept. 1993, Athens.

To break unexpected phenomena of energy efficiency markets, An in-depth approach to rebound effects in dynamics of domestic practices.

Dr. Sophie Némoz

Centre for Studies on Sustainable Development – Free University of Brussels, Belgium.

Abstract

Over the past thirty years, the energy use of appliances has been steadily decreasing with greater awareness of the importance of energy efficiency and innovations in technologies. However, overall household energy consumption for this period has risen. These counterproductive phenomena are commonly labelled the rebound effects, which are well-known among energy economists, but never attracted much attention. Climate policies that rest on the idea of energy-efficiency improvements due to technological progress tend to overestimate the potential saving effects because they ignore the behavioural responses evoked by the technological improvements. If the rebound effects have been seriously underestimated or neglected by both policy makers and stakeholders involved in the residential building sector, social sciences rarely explore theses dynamics of domestic practices beyond the evocation of the mechanism as an explanation. Thus, as a sociologist, my research project aims at revitalizing the discussion, by setting out the key issues raised by the approach to rebound effects in energy economics so as to help thinking about the bringing-in of a sociological model.

As it is notoriously difficult to quantify rebound effects, it is relevant to develop complementary, qualitative, methods to observe rebounds within households. In this paper, the social organization of everyday life is deepened as the main focus. From this point of view, it is immediately apparent that rather than concentrating on 'resources' like energy, the key issue is on of first understanding the services of these resources make possible: heating, washing, lighting, cooking etc. and then thinking about how these services change. The underlying idea consists in inspiring new ways of seeing embedding energy consumption in domestic practices, closer not only to what occurring at home but also to the concrete challenges of technological markets.

Acknowledgements

I wish to acknowledge the Centre for Studies on Sustainable Development (IGEAT – Free University of Brussels) and the other partners of the inter-disciplinary project entitled: Household Energy Consumption and Rebound Effect. For their contribution to this study, I thank very much the University of Anvers and the Institute ICEDD. Finally, I gratefully acknowledge the Belgian Science Policy Office, whose funding made this research possible.

Introduction

Energy innovation is a central process to meet growing demand for energy amidst concern about the safety of supplies and appeals for environmental protection. Over the past thirty years, the energy use of appliances has been steadily decreasing with greater awareness of the importance of energy efficiency and innovations in technologies. However, overall household energy consumption for this period has risen, due to larger homes, new services and new appliances. A common view of innovation is that innovation proceeds in a more or less linear model of diffusion from research through to engineering and applied development, and then to commercialisation. Nonetheless, looking at how demand for new energy-using products and services is developing, innovations are not turned out to be purely technological. Society has a persistent habit of using new technologies in ways that cause great surprise to innovators. This is the case of technical improvements in energy efficiency. A growing attention since the oil crisis towards energy efficiency on the demand side has played an important role. The energy efficiency of appliances is seen as a step for reducing the energy consumption of households. Efficiency is indeed defined as the rate of useful output(s) to total energy input(s) converted to provide the useful output(s). By using less energy to provide the same level of service, the efficient use of energy also implies reduced investments in energy infrastructure, lower fossil fuel dependency, increased competitiveness and improved consumer welfare. Thus, there are good arguments for the increase of energy efficiency of products and appliances: energy independence, energy cost and climate change. In most Western countries there is an increased focus on energy efficiency and energy reduction of households which is seen as vital for solving the climate problem. Citizens and households are responsible for a large share of global energy and the related emissions into the atmosphere. Energy efficiency measures related to residential appliances aim at finding new ways to accelerate the decoupling of energy use and CO_2 emissions from economic growth. If potential of energy efficiency improvements is still huge, there are also doubts that it will be enough to face the major problems linked to energy consumption. The European target of cutting greenhouse gas emissions by 20% by 2020 has generated a substantial body of energy efficiency policies. In 2010 the European Climate Foundation made the assertion that energy efficiency must be the foundation for success for Europe’s 2050 climate targets, but real-world observations indicate that energy savings realized in practice fall short of energy savings estimates based on physical principles incorporated in engineering models. A partial explanation of this trend consists in what is called “rebound effect” or “take-back”. As an increased consumption of energy services following an improvement in the technical efficiency of delivering those services, the rebound effect highlights a variety of tensions between the pursuit of wellbeing and the need to remain within ecological limits. Despite the decrease of the average unit energy consumption of most big appliances put on the market their total energy consumption has increased since 1990, as households possess and use more of these appliances.

The challenge of my talk is to provide a starting point for thinking systematically the links between the energy-related activities of households, and for conceptualizing the shift induced by an introduction of more efficient equipments. Appliances have totally changed our lives over the years. However, the behavioural responses evoked by technological improvements in energy efficiency are seriously ignored. The rebound effect due to energy efficiency improvements may therefore be understood in terms of technical-engineering versus behavioural-economic phenomena. Inferring from such a perspective on the occasion of my thesis about sustainable innovations in the residential building sector [1], my post-doctoral research focuses on an in-depth approach to rebound effects in dynamic of domestic practices. Given the potential importance of these counterproductive phenomena to climate change mitigation, the Centre for Studies on Sustainable Development (Free University of Brussels) entrusted me an interdisciplinary project which discusses the progress achieved in the energy efficiency markets of Belgium. The research in progress with engineers and economists offers a new and original development about the issue of rebound effects in dwelling energy consumption (fuels + electricity). As a sociologist, my main focus tackles the social organization of everyday life which constitutes a blind spot in the traditional framework of take-back. For instance, energy efficiency is defined as the ratio activity/energy. Although it depends on the definition of the service provided by an activity and its possible substitution, the existing studies on rebound effects discard any ‘behavioural interference’.

In the analysis that follows, it is firstly proposed to survey the scientific literature in giving special attention to the domestic sphere of residential appliances where the economic and technical sciences tend to overestimate the potential saving effects of improvements in energy efficiency. This introduction to the theoretical and empirical foundations of rebound effects will allow us to discuss the terms of the debate on the dynamics of social practices around efficient equipments. We will look further into the pertinence of micro-economic approaches to take-back. The interest in a complementary model of rebound effect will show up against that background. What is required is a shift in the conceptual framework of household behaviour, away from the narrow view of traditional neoclassical economics. A deeper understanding of energy use in everyday life will therefore be in order so as to identify the structure and the mechanisms behind the rebound effect at the household level.

1. Addressing the controversial issue of rebound effect in energy economics

The ongoing research conducted by the Centre for Studies on Sustainable Development mobilizes the economists of the University of Anvers and the engineers of the Institute ICCED, to contribute to an interdisciplinary study of rebound effects at the household level. The first bring-in of this project named: Household Energy Consumption and Rebound Effect (HECoRE), is a cross-disciplines overview of rebound phenomena. The documentary method is closely related to the discussion of what is termed the "rebound effect". For this key word, an exploration of tens articles through the search engine of *Google scholar* refers to various scientific literatures. Indeed, rebound effect is often mentioned in separated areas of sciences (energy economics, technical or social sciences, medicines). Nonetheless, the fact remains that a common meaning emerges from their state of knowledge. In different disciplines, the mechanisms of rebound effect follow the same structure of counterproductive dynamics. They evoke an unexpected reaction after solving a problem (whatever the nature) because the problem pops up again or causes other complications. Thus, the idea of rebound effect implies adverse phenomena to expected improvements. Regarding the energy efficiency gains of domestic equipments, it soon became clear that their take-backs are essentially the scope of economic studies. That's why the first part of the paper at hand is devoted to their state of art. It is indeed of paramount importance to begin by the analysis of the ways energy economics is currently debating on this controversial issue, before we can imagine a new conceptual framework which could dispel a number of misconceptions.

1.1. The limited relevance of rebound effect to official analyses

Firstly, it is a popular misconception that the notion of rebound effect is universally admitted by economic literature. Although the discipline accepts that energy efficiency improvements take back some of the expected energy savings, the relevance of rebound effect is still a vexed question among economists. Our review of the economic literature highlights that there is no standardized classification, terminology or even definition of tack-back. In the most general terms, rebound effects occur when efficiency gains lead to increase in consumption, largely as a result of efficiencies being reflected in lower prices. The rebound phenomena refer to non realized savings in the use of resources relative to potential savings in the use of these resources. Potential or technical savings are defined as a theoretical quantity of energy that could saved after an increase in energy efficiency, if the quantity of goods and services demanded or consumed were held constant. In energy economics, the starting point for conceptualizing the rebound effect backs on the "Jevons' Paradox" [2]. In 1865, the pioneering works of Stanley Jevons note that as technical improvements increase the efficiency with which a resource is used, total consumption of that resource may increase rather decrease. A century later, in 1980s, the economists Khazzoom [3] and Brookes [4] proposed a first systematic treatment which measures as a percentage of engineering savings that part of the initially expected energy savings, resulting from energy efficiency improvements, which is lost because of an increased consumption. The Khazzoom-Brookes or KB postulate, a term coined by Saunders [5], states that energy efficiency improvements justified to the micro-level leads to levels of energy consumption at the macro-level which are higher than they would have been in the absence of those improvements.

In the wake of these early contributions, the scale of observation constitutes a watershed of typical approaches to rebound effects in energy economics. In the discipline, one commonly focuses on the effects that the lower costs of energy services, due to technological improvements, have on consumer behaviour, both individually and economy-wide. Energy service means here any service provided to households and that uses energy, whatever is the energy vector or the technological system. The 'macro-economic' or 'economy-wide rebound effects' imply that decreased demand for a resource like energy leads to a lower resource price making new uses economically viable. The economy-wide rebound effect is "a controversial subject that has generated great debates among energy economists" [6]. In broad terms, one can distinguish two dimensions to the economy-wide rebound effect: a structural shift in activities and economic growth effect. Increased energy efficiency in manufacturing lowers overall production costs and therefore price of output which provides a competitiveness effect. As the HECoRE project focuses on the energy use by households, the view of rebound effects comes from the micro-side.

For cost-reducing energy efficiency improvements in the households sector, the micro-economic approach distinguishes direct rebound and indirect rebound effects. The ‘direct rebound effect’ is the increase in demand for an energy service (washing, heating, refrigeration, lighting, etc) when the cost of the service decreases as a result of technical improvements in energy efficiency. The direct effect combines a ‘substitution effect’ as price of energy relative to other inputs/consumption goods falls with an ‘income effect’ on households that is to say energy demand rises. Examples are households keeping their old fridge when buying a new one or putting efficient lamps in places previously not lit. Another classic example would be a homeowner who replaces a conventional boiler with a condensing boiler to increase the heating efficiency of his home, only to take advantage of the resulting decrease in home heating costs to increase the average room temperature, the amount of time the home is heated, and / or the number of rooms heated. The ‘direct rebound effects’ therefore refer to a change (increase) in demand for the energy service directly affected by the energy efficiency improvement and they are closely linked to the elasticity of substitution. A price or income elasticity is the ratio of the percentage of change in demand to a percentage of change in price or income. As for the ‘indirect rebound effect’, it also depends on the elasticities of demand for each of the goods or services, and the energy consumption associated with each commodity. Indeed, the ‘indirect (income) effect’ or ‘product substitution effect’ is the increased consumption of other final consumption goods and services by households. The individual may, for instance, decide to spend more money on ‘luxury’ services, e.g. going on holiday by plane. This is also an income effect, because the budget (or nominal income) of the households is still not used up after enjoying the (extra) quantity of the energy service under consideration.

Following this introduction to the scientific foundations of rebound effects, an extensive survey of the micro-economic approach to take-backs gives an account of divergences about the significance of rebound phenomena. As regards ongoing debate on low and high significance of take-backs, the most comprehensive, systematic overview of the empirical literature has been elaborated by the Energy Research Centre of the UK (UKERC) [7]. The UKERC research team concludes that existing investigations are rare, ambiguous and, often not very conclusive. The direct rebound effect is likely to be in the range of 10-30% for household heating and cooling within developed countries. The direct rebound effects for appliances seem to be smaller (less than 10%). However, UKERC regards most estimates as provisional and emphasizes that the methodologies need to be improved. The rebound phenomena are very difficult to quantify. There is little evidence for economy-wide rebound effect and the accurate measurement is limited. If quality continues to improve, the basis to draw any general conclusions seems to be inadequate for reasons of several methodological deficiencies. Indeed, the estimated direction and magnitude of the rebound effects will partly depend upon how energy service, energy efficiency and (energy and total) costs of the energy service are defined. First and foremost, energy is not the only input needed for energy services such as thermal comfort. Capital costs of durable goods have to be taken into account as well, especially when the more efficient technology is more expensive than durable with comparable characteristics but lower energy efficiency. Certain types of direct rebound effect may be constrained by the real or opportunity costs associated with increasing demand. Two examples are the opportunity costs of time and space. It is especially time-saving technological progress that frequently exerts a large influence on energy use. In this case, changes in energy use are merely ‘side-effects’ of households’ time-saving efforts [8].

Secondly, all empirical studies on rebound effects in energy economics assume ‘pure’ energy efficiency improvements and discard any evolution of goods and services demanded. Subsequently, the increase of equipment rate and more frequent use are largely neglected even as the associated energy consumption of appliances can be considerable. But, in micro-economics, the investigations of rebound effects concentrate on the demand of one particular energy service. Energy services such as heating, lighting, mobility, clean clothes or entertainment are provided through energy systems that involve particular combinations of capital, labour, energy carriers and materials. This kind of methodology based on the idea of ‘energy service’ supposes an exhaustive set of non-overlapping activities. So, it is much more difficult to estimate the energy efficiency gains when the service changes. The notion of service itself depends on the description. For instance, when the service is entertainment, high or low energy intensity device can provide a recreation.

Last but not least, in a multi-service model, the feedback could be stronger than suggested by the single-service model if substitutability is high. This is the case for a wide range of mostly small appliances such as computers, mobile phones, personal audio equipment and other home electronics. To look at indirect rebound effects, multi-service approaches are required. According to the micro-economic model based on the reversibility of investment in energy saving devices, households would constantly adjust their capital stock to new optimal levels whenever capital and energy prices change. This neo-classical assumption is an abstraction which may not always hold. It is equally obvious that in reality the pattern of consumption changes with income and over time. As models include the assumptions of their creators, the discussion need to be extended to a series of theoretical arguments for rebound effects at the micro-economic level.

1.2. A theoretical discussion of the micro-economic approach to rebound effects

The conceptual framework for micro-level analysis of the rebound effects in the household sector is the neo-classical model of consumer behaviour [9]. The theory has four basic elements to analyze 'rational choice': the consumer's available income, the prices of goods or services on the market, the consumer's preferences and the behavioural assumption of 'utility maximisation'. Given a limited income, a specific range of commodities to choose from, and a potentially infinite set of preferences, the consumer chooses commodities from those available such a way as to maximise his or her subjective utility within the constraints of his or her available income [10]. The micro-economy explains how individuals spend their financial resources, how they evaluate different possibilities and how they take purchasing decisions with the purpose of maximizing their satisfaction. Thus, households are seen as economic agents passively consuming what the market supplies. However, given that service markets are characterized by the great variety of products, comparing the available products requires considerable capacities for researching information and equally considerable capacities for analyzing it. The neo-classical model fails to take account of a number of constraints and other influential factors like the role of institutions and social relations, the different temporalities and spaces, etc. Contrary to rational choice, bounded rationality suggests that consumers face several limitations in processing information, such as availability of information, the cognitive limitations of their minds and the finite amount of time they have to make decisions. These constraints lead to deviations from rationality in certain circumstances.

Faced with numerous contradictions to the neo-classical assumption of fully informed consumers, a few neo-classical economists such as Becker [11] or Lancaster [12] have tried to redefine the axioms of consumer behaviour in micro-economy. The renewal of neo-classical thought aims at overcoming some of the conceptual difficulties with mainstream economics. The insatiable wants for goods as a stable way of thinking in current society seems to be too simplistic with regard to the plural rationalities of consumers. Energy decision-making encompasses a variety of decision making strategies that differ in some critical way from traditional utility maximization in order to reduce the cognitive burden of decision-making. Behavioural economics replaces the classic micro-economic assumptions of rational choice with bounded rationality or other decision methods [13]. Indeed, there is no real consensus between different models of bounded rationality in energy-related decision. The most distinct features of behavioural economics consist in the empirical investigation of consumer behaviour with a focus on the processes of decision making rather than its outcomes, and measures. If behavioural economics represent a notable advance in energy studies, they also refer to a very fragmented discipline. Its attempts to combine economics and psychology do not offer a complete alternative to explain the operation of markets.

The behaviour of consumers is not only instrumental but also axiological, institutional, cognitive and even subconscious. It depends on intentions or habits and routines according to the situation. Habit formation sustains certain consumption patterns over time. Besides, consumers tend to seek status symbols by purchasing goods not only for their practical value but also to affirm social status, group membership or self-esteem. In this perspective, the technological characteristics such as energy efficiency may be secondary in comparison with the socially agreed values of goods. Consumers are influenced by other households in society. Lastly, consumer behaviours are also sharpened by wider societal factors, including technological development, economic growth, demographic factors as well as institutional development or cultural context. But, the social character of individual behaviour or persistent conventions, even existing infrastructures and equipment remain underestimated in standard neoclassical approaches. It turns out that the micro-economic framework of rebound effects provides a narrow view of consumption patterns in the household sector. It seems therefore necessary to revitalize a long tradition in economic thought with more interdisciplinary insights into the domestic ways of using energy efficient appliances.

1.3. Looking further into the complex links between energy efficiency gains and other expenses at the household level

To extend the approach to the rebound effects of energy efficiency markets in the household sector, the HECoRE project goes beyond the walls of the economists' laboratory. As a sociologist, my analysis of take-backs is grounded on the fieldwork of embedding energy consumption in ordinary practices. What is that keeps increasing numbers of people living in resource intensive ways? The question is raised by the social literature without giving special attention to rebound phenomena. Given the difficulties in quantifying their significance, there is a need to develop one of their first qualitative studies. The objective of this paper is to summarize the major lessons learned from this method of approach to rebound effects. To analyse the meaning of their economic concept for households' practices, the first step of this research in progress was a focus group with eight individuals selected according to criteria based on household income, composition, age, gender and dwelling location (big city, small town, suburb, countryside). All respondents realized energy savings at home. In order to avoid as much as possible any bias, households were defrayed (40 euros per participant). It was hence easier to involve lower groups of the population and people who are not especially interested in the question of energy conservation. The energy-efficiency equipment of their practices constitutes the front door of a questionnaire focused on their energy savings and their spending. The idea behind the questions from which this approach starts and that it deals from its context is an exploration of spontaneous representations linked to the take-backs in everyday life. In the questionnaire, several questions were asked to evaluate the level of knowledge in the Belgian public of the issue thus labelled by energy economics. Without imposing a scientific definition, the purpose is to survey the ordinary experiences of rebound viewed from the angle of households. The diversified panels are advantageous to maximize the investigation of different perspectives within a group setting. Indeed, the principle of collective interviews is that group processes can help people to clarify how they save energy at home, but also what they think about and why they think that way.

As a first result of the focus group with households, the qualitative method applied to energy savings and spending was proving to be a heuristic approach to rebound effects at the household level. It permitted exploring how consumers make links between energy efficiency gains and other expenses. If individuals do not precisely calculate how much they save thanks to their investments in efficient appliances and their rational use, the various efforts made to this end lead households to spend more money in leisure activities (home cinema, DVDs, video games, equipments for sports, going on holiday by plane or by personal car, rides in motorbike during week-ends). From their point of view, we can speak about rewards for the economic, social, cognitive, mental and physical efforts revolving around the adoption of material equipment in energy efficiency. This kind of interpretation refers to what was recently called "mental or psychological rebound effect" [14]. Precisely, this emerging category of take-backs underlines that technical innovations improving environmental impact can have negative impacts on consumer behaviour because customers "feel good" or "less guilty" about their choices and they pay less attention to consumption. Regarding this "diminished concern", the collective interview of households has shown that the respondents consider energy consumption as a right. In their discourses, the spending of energy savings was described as a compensatory dynamic. In energy economics' terms, these practices of leisure evoke what is called "indirect rebound effect". The method allows a comprehensive approach to its determinants. The focus group with households enhanced the importance of both material and socio-cultural dimensions at stake. The data thus collected also suggested a close link between the level of energy consumption and the energy bill. People are firstly concerned with the stability of their global energy bill. At the intermediary stage of the HECoRE project, the engineers of the ICEDD provided quantitative data that confirm such a pattern of household energy consumption.

The integration of price dimension in policies and measures appears as a necessary condition in order to enhance their effectiveness. By consequence, the next step of the research will go further into some relations between energy price and demand. The main objective is to be able to make recommendations about suitable instruments to mitigate rebound mechanisms, with a focus on energy pricing issues. The acceptability or even the 'desirability' of such energy policies and measures are crucial to transform a theoretical reflection into effective policies and measures. On the occasion of the first survey of households' opinions, the respondents had not considered tax increase as a panacea. For them, this kind of measures could imply more deprivation and less enjoyment. We can begin to scratch the surface of this statement, by integrating in a common conceptual framework: the criticism of the neo-classical economics, the need to take into account the infrastructures and the socio-cultural context of energy-related practices. The theoretical model of the research is built in broadening the understanding of rebound with insights from social sciences and in exchanging the resources produced by the economic and technical expertises. The reviewed literature draws up a general picture of the lack of clarity around which energy efficiency policies are effective in driving the decrease of energy consumption at the household level. This paper seeks to reduce this knowledge gap by offering a framework to better understand the different dynamics what is called 'rebound effects' in generic terms.

2. Re-thinking the dynamics of rebound as socio-technical transitions of practices

For at least 40 years now, studies from different disciplines (psychology, sociology, economics …) have shown that increased demand for energy from households depends on a wide range of mechanisms. In the 1970s, the oil and energy crises raised awareness for questions about the development and the determining factors of energy consumption and efficiency. The scientific field had predominantly adopted a technical stance based on engineering sciences and had focused on the technical side of optimizing efficiency. To include behavioural factors in this field, psychological and economic approaches were strongly developed in the 1970s and 1980s. In parallel to these disciplinary perspectives on the complexities of energy consumption, social sciences had investigated energy consumption from various angles. The efforts to conceptualize and explain the transformation of households' energy uses demand and require engagement with a significantly different set of concerns and considerations. As regards the rebound effect, we will further integrate the insights of *practice* and *transition* theories into a new framework of take-backs. Firstly, the emphasis will thus be put on the socially mediated nature of these increases in energy consumption and their socio-cultural and infrastructural dimensions. Far less attention has been paid to the co-evolutions between technologies, behaviours and images. To discuss their important but neglected implications, it seems relevant to consider how to develop a joint approach which combines what can be measured with what makes sense at the household level. The underlying idea of re-thinking the dynamics of rebound as a socio-technical transition of practices is to transform an abstract reflection into a heuristic model of diverse determinants at stake in everyday life. If models necessarily simplify the real world, case studies such as home heating can secondly push flesh on the conceptual bones of practices in the socio-technical transition of energy efficiency improvements.

2.1. Dissecting the dynamic interrelations between technology and everyday energy use through the theories of practices and technological transitions

Given that the technical aspects of energy use are frequently left behind in analyses originating in the fields of social or cultural/anthropological sciences, one possibility to remedy this shortcoming could be encountered in taking a socio-technical stance, focusing on the impact of energy efficient equipments on the spheres of daily activities. Thus, the first step of our ongoing study with my colleague Wallenborn consists in defining the appropriate unit of analysis to map how the material, cognitive, institutional and symbolic factors interact in influencing the significance of rebound effects at the household level [15]. From this perspective, a 'practice theory' approach has been chosen as the basis of our sociological framework. In the past few years, social practice theories have been used, discussed and developed in the sociology of consumption, namely in the field of energy consumption. If Schatzki [16] and Reckwitz [17] are both authors who are the most often quoted in reference to this train of thought, its sources of inspiration are multiple as well as diverse. Indeed, practice theory is a promising approach rather than a conceptually achieved theory. One of its conceptual interests rests on the articulation of traditionally separated concepts in sociology such as those of Bourdieu, Giddens, Lyotard, Charles Taylor, Garfinkel, Foucault, Latour, … The integrated analysis of their different sociological insights offers a multi-dimensional view of consumer behaviour, closer to what occurring in ordinary life. The basic principle of the practice centred framework postulates that its unit of analysis is the smallest in social sciences. As Reckwitz precises, two senses need to be distinguished in the term of practice: on the one hand, it means human action as a whole (*Praxis)* and, on the other hand, practices (*Praktik*) refer to a "theory of social practices". In this last sense, « A 'practice' (Praktik) is a routinized type of behaviour which consists of several elements interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know how, states of emotion and motivational knowledge. » (Reckwitz, 2002, p. 249). This « new » approach has the explicit ambition to complexify the psycho-social models based on attitudes and individual behaviours (more or less rational), without necessarily adopting a holistic approach where the social structures are considered as causal, nor an epistemological relativism. Social order and individualities result from practices which can be identified and described as having an intrinsic value for "practitioners". If the processes of imitation are crucial for the creation and the reproduction of social facts, it is important to note that an agent does not imitate another individual but the practice updated by this individual [18].

At the moment, different authors are debating to determine the number of dimensions which should be taken into account by a practice theory [19]. We can discern the following components: materiality, infrastructures and objects; competences, skills, know-how and practical understanding; norms, procedures and institutionalized knowledge; engagement, symbolic meanings and representations.

Beyond the number of elements involved in a practice, what matters is their way of being present and linked to each other. Thus, the conceptual framework of practice theory can be sufficiently integrative to encompass most of the data coming from a lot of disciplines and other field studies. By consequence, another interest in applying this theoretical approach to rebound effects consists in keeping in mind all the dimensions of problem. In the case of domestic energy consumption, the practice centred theory has several advantages presented below. To the extent that households do not consume energy, but use a series of appliances and resources which provide them different services [20], it makes sense to take practices as unit of analysis. Indeed, a practice theory approach to take-backs is able to move away from an expert understanding of reality and to approach the lay household's one. From a scientific viewpoint, it is particularly obvious that there is a lack of studies investigating the matter of rebound from the perspective of the people concerned; focusing on their energy practices, conditions of action, and coping strategies. As a matter of fact the rebound effect describes the discrepancy between potential (expected) and actual (realized) energy savings, which stems from behavioural reactions of economic agents in contrast to keeping the status quo [21]. More broadly the fact remains that people give sense to practices. Cooking, washing body, chatting on the web, are activities whose individuals have both practical and discursive consciousness. In other words, a competent "practitioner" is an agent able to appropriate a group of elements in order to reach a precise goal, who has the possession of adequate tools, and whose behaviour needs a certain degree of attention. Furthermore, the eminently material characteristic of consumption is immediately included in the analysis of practices. Their sociological approach extends the psychosocial view of consumer behaviour to incorporate both internal and external elements of psychological disciplines. Even if many theories in psychology offer insights into the relevance of factors other than economic ones as regards the micro-level of energy consumption such as attitudes and values, psychological as well as economic approaches rely on individualist models for consumer behaviour which are not socially embedded and neither take into account the socio-cultural context nor the infrastructural conditions of actions like those of built environment.

However, homes, offices, domestic appliances and other material objects play a major role in our lives. The predominant effect of habits and routines explains that not many of us question exactly how and why we perform so many rites associated with everyday use of energy technologies. A practice theory approach gains insight into these factors of behavioural inertia, by explicitly considering them through tacit knowledge and practical consciousness required by the accomplishment of a task. Furthermore, the fulfilment of a practice is actively linked to heterogeneous elements which imply forms of resistance to change. Indeed, our practices are enrolled not only in the material environment, but also in social norms and routines which reinforce each other. As Shove has shown [22], social norms and conventions constitute a key factor of explanation for the development of practices such as the case of weekly bathing which was replaced by daily showering in few decades. In Shove's analysis, there is clear evidence supporting the view that routine consumption is controlled by conceptions of normality and profoundly shaped by cultural and economic forces. Expectations of comfort, cleanliness and convenience have changed radically over the past few generations. If they evoke different needs, they also refer to a social trend that can be adapted. This movable perspective is the last advantage of practice theory for re-thinking the dynamics of consumption labelled "rebound effects" in energy economics. Viewed from this sociological angle, practices are differentiated and dynamic in an intrinsic way. Both dimensions have been underlined by Warde [23]. It is a social fact that individuals accomplish a same practice in very various ways. We can even observe resistances to the accomplishment of some practices and the emergence of alternative ones. In other words, our practices evolve. They have a history with a beginning, a development and an end. As the implementation of a practice requires an interconnecting link between distinctive elements, we can understand how these components chain to each other, by accumulation at certain periods or by dispersion another time.

To analyse the evolution of energy-related practices whose significance of rebound effects is relatively well-known among energy economists, the renewal of their conceptual model is not only based on the practice theory, but it also borrows from the "theory of technological transitions" its main concepts: socio-technical regime, niche, landscape [24]. If the practice theory leads us to a comprehensive approach to heterogeneous components of tack-backs and no longer strictly focused on energy efficiency, the transition theory is good at describing the multi-level interactions of such elements whose timing of change are variable. The socio-technical regime of given sector (mobility, energy, food, etc.) is defined as a series of institutions whose connections can display the link between production and consumption: industrial networks, scientific and technical skills, sectoral policies, markets and users, technology, infrastructure, culture. All the relations between actors make up the socio-technical regime as a dynamically stable whole. A socio-technical regime is actively created and reproduced by different social groups. The production and reproduction of relationships between actors stabilize the entities of system. The concept of technological niche describes the starting level of innovations. These novelties constantly emerge, but their forms are unstable until they have not been integrated into a regime. The performance of new technologies is generally weak with regard to the norms of regime, and innovations disappear before being stabilized. That's why these niches should be protected, "sited on" if we want to give them a social future. Finally, the socio-technical landscape refers to the environment on that change needs a very long time. At this level, there are the whole of extern variables which frame the possible evolutions of regime: international and national policies, macro-economy, demography, climate change, cultural mutation, etc. This three-level approach is effective to follow the dynamics of transition from a socio-technical regime to another. An innovation can develop in a unique or several niches thanks to various processes: training, improvements (notably in performance), price decrease and support for powerful groups of society. The irruption of an innovation disturbs the socio-technical regime in place and recomposes it by transforming for instance the relationships between actors. At the level of landscape, changes can also pave the way for the development of innovation at the level of regime. The new socio-technical regime is stabilized when the innovation is broadly adopted and when the set of practices become an identifiable configuration.

In this integrated approach, we substitute technological innovations for practices and social norms are located within landscape. Indeed, they tend to concern several given sectors and they evolve in a slower way than technologies. Nevertheless, new social norms can emerge and favour the multiplication of new niches. Of course, the decrease of energy consumption lets us to think about an emerging norm in our society and which contradicts with other social norms. As for the socio-technical regime, it is characterized by users' habits and routines which gather a great variability of uses within a same practice. To the extent that the accomplishment of a practice makes thanks to the cohesion of heterogeneous elements and that a practice is varied in an intrinsic way, the novelty of a practice can not be as easily spotted as for a technological innovation. But the case study of domestic energy consumption, in particular home heating, can show the clear indicators of practices in transition whose conceptual model proposes to follow. Technical equipments such as central heaters are not only constituents of shifts in our social practices, but also a concrete way of questioning energy efficiency. This paper examines whether and how the rebound effects at the household level can be understood within this perspective.

2.2. Reviving the sense of rebound effects in home heating as practices in socio-technical transitions

As energy use, in most cases, is invisible and unspoken of, silently accompanying everyday actions and routine, the rebound effects linked to energy efficient improvements in households' equipments are proving to be unexpected phenomena. If we take the social organization of daily life as the main focus, it is immediately apparent that rather than concentrating on 'resources' like energy, the key issue is on first understanding the services of these resources make possible: heating, washing, lighting, cooking, etc. and then thinking about how these services change. With regard to both scientific and political concerns for energy efficiency in the sector of heating [25], awareness for the factors determining increases in its energy consumption is an important ambition of the alternate model applied to this practice. According to this original framework which does not place the social in individuals, but in the practices themselves, the paper at hand presents the analysis of efficient technologies experienced on average in the everyday life of Belgian households. Belgium energy consumption per square meter in residential buildings is more than 70 percent higher than the European average [26]. The observation of rebound effects needs a long time perspective since they refer to the consequences of prior energy savings provided by technical progresses in energy efficiency. From 1961 to 2004, for instance, how have they transformed the average practices of home heating? Contrasting with the dominant perspective of economic studies on rebound effects, our new modelling analyses the social uses and processes of co-construction of technology and society, given the many variables involved over a long timescale.

To be recognized as a practice, a certain degree of repetition is needed. It is the regular performance of a practice, of its doings and sayings, which maintains a practice as an entity. Social interactions is framed by a variety of constraints that, in turn, strongly contribute to the regularity of communication, resource allocation, preference formation and problem solving that characterise most social phenomena. Behavioural changes linked to energy use are no exception – whether successful or not. What have happened in the case of home heating? In this model of understanding, basing on empirical data, the long time perspectives of emerging energy technology progress are scrutinized. In order to evaluate energy practices and their evolution, we started on integrating the longitudinal data collected by the Institute

ICEDD in Belgium. If we thus compare the current situation of space heating in Belgian households with their common practice in 1961, we can observe that central heaters are actively appropriated or domesticated to the detriment of coal stove. Nowadays, 70% of inhabitants in Belgium have a central heater contrary to only 10% in 1961[1]. In the material field, when a central heater is acquired and enters an average household, the installation of energy efficient technology is accompanied by the putting in radiators and pipes, even by an extension of surface area per household. However, all the residential stock is not changed. Belgium's housings are relatively old because of low demolition rate (at 0,075 percent a year one the lowest in Europe) and growth in the building stock of only 1 percent, compared to a 1, 5 percent average among Belgium's peers [27]. It is an element at the landscape level whose timing of innovations is very slow-acting.

On the other hand, we can notice a shift in the socio-technical regime of heating. During the past winters, indoor temperatures were between 25 degrees C in the kitchen and 15 degrees C in other rooms. Nowadays, the heating is turned on in all the rooms of housing which are routinely heated to 21 or 22 degrees C. This is what households come to expect and when that happens, anything else is deemed odd. Therefore, heating practices are also affected by social norms. The cold part of the year no longer signifies having to put on various layers (that was, in most cases, at least two pairs of warm socks, sometimes even long underpants, and several layers of clothes on the upper part of the body) inside dwelling. Whereas central heater is now integrated into daily life and is almost everywhere, concentrating the warmth in on single room as well as using clothes and blankets to preserve body warmth in a cold housing is contrary to the current trend and its conceptions of normality. Thus, the practice of home heating has evolved and contemporary regimes of comfort are constituted through a range of regulations and technical procedures, knowledge of thermostat's functioning, understandings of ordinary indoor clothing, global building materials and air-conditioning industries, conventions of ventilation, sweat and smell, and actual built environments designed and run in a particular way. The influence of norms, not only technical but also behavioural such as these accumulated in habits, have been theorized in the field of social practices [28].

Beyond perceptions, feelings or sensations, an important renewal of social images is remarkable in the rising of both power and efficiency provided by central heaters, compared to coal stoves. Formerly, the ignition of glowing ambers in a unique room was an opportunity to bring together all the members of family around only one seat and to share together different practices in everyday life. Between promiscuity and conviviality, cooking, washing bodies and clothes fell to women like the responsibility for keeping an eye on the ignited fire at the risk in putting out [29]. Currently, although these tasks remain predominantly feminine, we no longer imagine them near heater, nor in front of every member of households, but in an individualized way. The better technical efficiency of gas boiler, or electric radiator, deeply disrupts our connections with domestic space and time, leading to the dispersal of energy-related practices at home. Regarding cooking, showering, washing, all these practices jointly done in the old days are from now on in a new compartmentalization which separates different sectors of household activities in everyday life and in domestic spaces. It is important to stress that this drawing of the practice as an entity, is not only visible to analysts. This entity makes sense to the practitioners themselves. This meaningfulness does not mean that people have a discursive knowledge of those practices; it can also be practical and implicit. Finally, the socio-technical transition of heating from coal stove to central heater offers a new interpretation of direct rebound effect at the micro-economic level. The phenomenon measured by economists no longer appears as the outright result of individual adjustments to the cost decrease of heating service. As regards the practice of heaters, the dynamic of rebound effects is more largely the consequence of a shift in the material, cognitive and symbolic system of practice which makes possible an current energy use not only spatially extended, but also concomitant with other energy-related practices. Thus, the introduction of a new appliance does not necessarily change the patterns of practices in the sense of more energy efficiency.

3. Concluding remarks about the current knowledge of rebound phenomena and further developments

In a tentative concluding discussion the approach to rebound effects as practices in socio-technical transitions reflects a different thinking of energy consumption which gives new perspectives on energy efficiency and path dependence. To quantify the significance of rebound phenomena, economists have to

[1] Source : DGSI.

back up their evaluations with hypothesis far removed for real conditions of daily practices. Thus, efficiency measures the amount of energy necessary for a given service and only considers the technical dimension of practices. In other words, the energy services used by a household are reduced to an exhaustive set of non-overlapping activities and whose sum corresponds to the total energy consumption of a household. But the idea of energy service is not precisely defined. Besides, practices are supposed to be identical when technology changes, whereas it is rarely the case. The hypothesis is only possible when technology and behaviour are separated by an abstract way like the approach developed by laboratories. Subsequently, the links between services and their evolutions can not be taken into consideration, although our model based on the theories of social practices and technological transitions provides a new interpretation of rebound effects. The next step of our research proposes to re-evaluate the absolute energy consumption for the heating practice and its transition in the long term. This quantitative approach to rebound effects at the household level will try to take account of the material, cognitive and symbolic factors driving the energy efficiency of heating practice. As the paper has presented this three-level approach to take-backs, their estimates will suppose that the energy efficiency of a daily practice not only refers to the technical performance of domestic appliance, but also depends on the material network in which the last is more largely integrated, and on the habits of use, their temporal and spatial parameters.

The energy performances of heaters have constantly been improved since they went out their “niches”. If the efficiency of practice is measured in relative unities (kWh/m² for space heating), we can understand that total energy consumption are likely to increase because the surface area of housings and their number have been multiplied. Nevertheless, our explanation is different. Household’s daily use of space heating has not only been modelled as depending on the perceived cost of space heating service. Focusing on the evolution of practices, this original analysis has indeed shown that their implementation in a socio-technical regime leads households to organize their activities in a different way. The meanings of these transformations are diverse and the key issues of comfort, commodity and temporal gains have notably been underlined to the extent that they allow the spread of new technical objects. Thus, the practices accomplished by a household have been multiplied and diversified. In the socio-technical transition of heating from coal stove to central heater, practices have been scattered at home as and when new objects were acquired by households. Even if each practice individually considered is more “effective” compared to the past, the new agencies of practices generate an increase in energy consumption at both individual and societal levels. Without possessing an understanding of the material, socio-cultural and cognitive factors influencing energy consumption, any measures taken to stimulate energy efficiency and energy saving are only going to have minor repercussions. The pieces of the picture that mono-disciplinary approaches provide for the overall understanding of rebound matter are necessary, but in themselves largely not sufficient so as to explain the multi-dimensional phenomenon of energy consumption. Thus, an interdisciplinary socioeconomic viewpoint could offer a broader and much more diversified perspective, suited to the complexity of energy use.

References

[1] Némoz S. *"Eco-housing”: a sustainable innovation… Sociological analysis of residential ecology in France as through Finland and Spain*. Ph. D in sociology, Paris Descartes, Sorbonne, 2009.

[2] Jevons W. S. *The Coal Question – An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-Mines*. MA, II. D., F.R.S., Augustus M. Kelley Publisher, New York, 1865 (reprint in 1965).

[3] Khazzoom D. J. *Economic implications of mandated efficiency in standards for household appliances.* Energy Journal. 1, 1980, pp. 21-40.

[4] Brookes L. *A Low Energy Strategy for the UK by G Leach et al: a Review and Reply*. Atom. 269, 1979, pp. 3-8.

[5] Saunders H. *The Khazzoom-Brookes Postulate and Neoclassical Growth*. Energy Journal. 13, 1992, pp. 131-148.

[6] Dimitripoulos J. *Energy productivity improvements and the rebound effect: An overview of the state of knowledge*. Energy Policy. 35, 2007, pp. 6354-6363.

[7] Sorrell S. *The rebound effect: definition and estimation*, International Handbook on the Economics of Energy. Eds.: Evans J. and Hunt L. C., Edward Elgar, Cheltenham, 2009.

[8] Binswanger M. *Technological progress and sustainable development: what about the rebound effect?* Ecological Economics. 36, 2001, pp. 119-132.

[9] Berkhout P.H.G. Muskens J.C. and Velthuijsen J.W. *Defining the rebound effect*. Energy Policy. 28, 2000, pp. 425-432.

[10] Jackson T. *Motivating Sustainable Consumption a review of evidence on consumer behaviour and behavioural change*, Sustainable Development Research Network, Sussex, 2005.

[11] Becker G. S.. *A Theory of the Allocation of Time*. The Economic Journal. 75, 1965, pp. 493-517.

[12] Lancaster K. J. *A New Approach to Consumer Theory*. The Journal of Political Economy. 74, 1966, pp. 132-157.

[13] Dubin J. and McFadden D. *An Econometric Analysis of Residential Electric Durable Good Holdings and Consumption*. Econometrica. 52, 1984, pp. 345-362.

[14] Girod B. De Haan P. Scholz R. W. *Consumption-as-usual instead of ceteris peribus assumption for demand, Integration of potential rebound effects into LCA*. International Journal of Life Cycle Assess. 2009. DOI 10.1007/s11367-010-0240-z.

[15] Nemoz S. and Wallenborn G. *Comment comprendre les effets rebonds dans la consommation domestique d'énergie ?* Pour une socio-anthropologie des pratiques en transition. Paris, L'Harmattan, coll. "Socio-anthropologiques", 2011.

[16] Schatzki T. *Social Practices. A Wittgensteinian Approach to Human Activity and the Social*. Cambridge, Cambridge University Press, 1996.

[17] Reckwitz A. *Towards a Theory of Social Practices: A Development in Culturalist Theorizing*. European Journal of Social Theory. 5, 2002, pp.243-263.

[18] Røpke I. *Theories of practice – New inspiration for ecological economic studies on consumption*. Ecological Economics. 68, 2009, pp. 2490-2497.

[19] Gram-Hanssen K. *Heat comfort and practice theory. Understanding everyday routines of energy consumption*. Proceedings of the SCORE Conference (Brussels, Belgium – March 2008).

[20] Wilhite H. Nagakami H. Masuda T. Yamaga Y. and Haneda H. *A cross-cultural analysis of household energy use behaviour in Japan and Norway*. Energy Policy, 24, 1996, pp. 795-803.

[21] Lorentz A. and Woersdorfer J. S. Energy-efficient household appliances and the rebound effect – A model on the demand for washing machines. Max Planck Institute of Economics (Jena – June 2009).

[22] Shove E. *Comfort, cleanliness and convenience: the social organization of normality*, Oxford, Berg, 2003.

[23] Warde A. *Consumption and theories of practice*. Journal of Consumer Culture. 5, 2005, pp. 131-151.

[24] Geels F. W. *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study*. Research Policy. 31, (8/9), 2002, pp. 1257-1274.

[25] Stern N. *The Economics of Climate Change. The Stern Review*. Cambridge, CUP, 2006.

[26] Denis N. Eykerman P. Peeters C. and Verhoeven R. *Pathways to World-Class Energy Efficiency in Belgium*. Belgium, Mckinsey & Company, 2009.

[27] Marbaix P. and van Ypersele J. P. *Etude sur la réduction des émissions de CO_2 dans le parc immobilier du futur*. Belgium, UCL – Institut of Astronomy and Geophysics G Maître, 2009.

[28] Taylor Ch. *The explanation of behaviour*. London, Routledge and Kegan Paul, 1964.

[29] Stephany P. *Les années 60 en Belgique*. Brussels, Ed. Racines, 2006.

Advertising and Residential Energy Savings

M. Sulyma and K. H. Tiedemann

BC Hydro

Abstract

Electric utilities are widening the scope of energy conservation activities beyond traditional demand side management incentive programs to encompass broader advertising and information activities. Advertising and information programs have the potential to provide deeper savings at relatively low costs to utility companies and to ratepayers. This paper reports on an aggressive advertising program conducted by BC Hydro and aimed at reducing electricity consumption among its residential customers. The paper employs econometric methods to model the determinants of energy awareness, attitudes and behaviours. Key results are as follows. (1) An increase of cumulative advertising of 1,000 GRPS increases unaided awareness of Power Smart by 2.2%, while an increase of cumulative advertising expenditures of $1 million increase unaided awareness of Power Smart by 3.1%. (2) An increase of unaided awareness of Power Smart of 1 percent increases the overall attitude towards energy efficiency by 0.53%, increases knowledge of energy efficiency by 0.33%, increases the attitude that the participant is an active energy conserver by 0.75%, and increases the attitude of planning to reduce energy consumption by 0.53%. (3) An increase of the overall or composite attitude towards energy efficiency of 1 percent increases the performance of lights off when no one in room by 0.74%, increases performance of minimum number of lights on by 1.163%, increases the performance of turn television off by 1.58%, increases the performance of night temperature set back by 0.58%, increases the performance of day set back by 0.92%, and increases performance of turn water heater off by 1.10%. (4) For F2008, estimated energy savings are 9.4 GWh and estimated peak savings are 2.4 MW. For 1F2009, estimated energy impacts are 18.7 GWh and estimated peak impacts are 4.8 MW.

Introduction

Research on energy conservation has been dominated by an engineering economics paradigm, in which economic agents adopt those technologies and practices that are cost effective. Some references to this literature include Duke and Kammen [1], Golove and Eto [2], Horowitz and Haeri [3], Jaffe and Stavins [4] and Joskow and Marron [5]. Within this literature, analysis of energy savings opportunities typically proceeds by estimating net life cycle costs, and then assuming that the technologies, practices and behaviours with the best life cycle costs will be adopted by economic agents, whether they are businesses or households. From a public policy perspective, the most effective policy initiative is one that most cost effectively promotes improvement in adoption and efficient use of lighting, appliances, motor systems, HVAC systems and building shells. Demand-side management programs have focused their attention on market barriers to the adoption of efficient technologies and developed instruments to overcome these barriers.

The rich behavioural literature on how customers actually make decisions on how they use energy has had, until recently, relatively little impact on energy efficiency policies. Some references to this literature include California Energy Commission [6], Janda et al. [7], Lutzenhiser [8], Stern [9], Sahota et al. [9] and Tiedemann et al. [10]. This behavioural literature typically examines the actions of economic agents in specific and well-defined contexts with a view to understanding how and why they make decisions on energy use and on energy conservation behaviours. Interest in the behavioural literature began to increase both during and after the California energy crisis of 2000-2001, where the traditional hardware solutions to energy conservation were initially promoted. But the substantial energy demand reductions that were actually observed appeared to be due, upon detailed examination, primarily to conservation behaviours promoted by mass media and by social marketing. This suggests that it may be useful to try to more explicitly model the role of residential and business customers in securing conservation benefits, and to build models that will help understand why some customers adopt energy efficient technologies while others do not adopt them.

Given the wide range of objectives, methodologies and data employed in these studies, it is difficult to summarize the findings of this literature. But a core set of findings from this literature might include the following:

- Avenues for Intervention. Two main avenues of intervention to encourage pro-environmental behaviour have been identified: information and incentives. The information intensive approach assumes that appropriate information will change attitudes which will in turn change behaviour. The incentives approach assumes that taxes and subsidies will change private costs and benefits and consequently change behaviour (Jackson [11]).

- Impact of Information Programs. Information can affect attitudes and behaviours, but the chain of linkages from program activities to awareness to attitudes and to behaviour has rarely been comprehensively examined, although individual links in this chain have been explored, often through experiments. Some researchers have emphasized the difficulties in changing behaviour through information campaigns (Geller [12] and McKenzie-Mohr [13]).

- Impact of Incentive Programs. Incentives can also affect attitudes and behaviours, and the positive evidence for the impact of incentives is more comprehensive and persuasive. But against this, some observers argue that the impact of incentives is often weak, unpredictable and uncertain (Sorrell et al. [14]).

Although there is large literature touching on various aspects of residential energy savings, there appear to be few studies which have attempted to measure the impact of advertising programs on energy savings. This paper attempts to help fill this gap. The next section summarizes the data and method used in the study. This is followed by a detailed review of the study results. The final section provides a summary.

Data and Method

This study uses primary data collected over two years to understand the determinants of customer awareness, customer attitudes and customer behaviour. Information on the advertising stock is obtained by cumulating information from the advertising blocking charts. Information on awareness, attitudes and behaviour comes from the periodic Power Smart Tracer surveys, which have sample sizes of 600 residential customers. Two measures of advertising stock are used: cumulative gross rating points (GRP) and cumulative expenditures. A gross rating point is a measure of target audience exposure to an advertisement. Gross rating points are defined as the average number of exposures per target audience member times 100. A single measure of awareness is used: unaided awareness of Power Smart. Three measures of attitude are used: knowledge of energy efficiency; active energy conserver; and plan to reduce energy use. We also use a composite attitude measure, which is the average of the three attitude measures, so we can use a simple model given the small sample size. Finally, six measures of behaviour are used: lights off when no one in the room; use minimum number of lights for the task; turn television off if no one in room; night temperature set back; day temperature set back when no one at home; and water heater off if home unoccupied for three days or more. Although additional behavioural measures are now being tracked through the customer surveys, they were not included in the surveys for the full period we analyze, and so they were not available for this analysis.

We follow and extend the literature on behavioural change and model the following linkages, which we assume to be causal in nature. The subscript “i” refers to a particular advertising stock, awareness, attitude or behaviour, and the subscript “t” refers to the month.

(1) $\text{Stock}_{it} \rightarrow \text{Aware}_{it} \rightarrow \text{Attitude}_{it} \rightarrow \text{Behaviour}_{it}$

Each of the three linkages is represented by a particular arrow in this representation, and it is modeled by a separate linear regression. We are thus able to examine and test the validity of each of the separate linkages in the causal chain.

We are ultimately interested in the impact of behavioural change on energy consumption and peak, so for each of the six behaviours which we examine, we use the following algorithms to estimate the change in energy and peak, where we suppress the subscripts.

(2) ΔBehaviour = ΔStock*∂Aware/∂Stock*∂Attitude/∂Aware*∂Behaviour/∂Attitude

(3) ΔEnergy = ΔBehaviour*∂Energy/∂Behaviour

(4) ΔPeak = ΔBehaviour*∂Peak/∂Behaviour

The change in advertising stock comes from the advertising blocking charts. Because the regression models are linear, the three partial derivatives for Equation (2) are given by the relevant regression coefficients from the regression models. The partial derivatives which are used for Equation (3) and Equation (4) come from the behavioural research undertaken for BC Hydro's Conservation Potential Review.

Results

The first step in the analysis is to understand the determinants of awareness of Power Smart. Analysis of the determinants of unaided Power Smart awareness is based on the regression model shown in Table 1. The second column models unaided awareness of Power Smart as a function of a constant term and the cumulative stock of advertising as measured by cumulative GRPs. The third column models unaided awareness of Power Smart as a function of constant and the cumulative stock of adverting measures as the sum of expenditures in thousands of dollars. Both equations have good explanatory power with adjusted R-squared values of 0.62 and 0.61 respectively, and the coefficients are statistically significant at better than the 5% level. Model (1) says that an increase of cumulative advertising of 1,000 GRPS increases unaided awareness of Power Smart by 2.2. Model (2) says that an increase of cumulative advertising expenditures of $1 million increase unaided awareness of Power Smart by 3.1%. These are substantial impacts.

Table1. Determinants of Unaided Awareness

	Unaided awareness (1)	**Unaided awareness (2)**
Constant	20.1*** (1.65)	20.2*** (1.69)
Cumulative GRPs	0.0022*** (0.00040)	-
Sum expenditure	-	0.0031*** (0.00058)
Adjusted R^2	0.62	0.61
F	30.6 (0.00)	28.6 (0.00)

Note. One, two or three asterisks means coefficient is significant at 10%, 5% or 1% level respectively.

The second step in the analysis is to understand the determinants of attitudes towards energy use. Attitude refers to the percentage of respondents who strongly agree with the statement. Analysis of the determinants of attitudes is based on the regression models shown in Table 2. Column (1) models a composite attitude towards energy use as a function of a constant term and unaided awareness. Column (2) models knowledge of energy efficiency as a function of a constant term and unaided awareness. Column (3) models respondent is an active energy conserver as a function of a constant term and unaided awareness. Column (4) models respondent plans to reduce energy use as a function of constant and unaided awareness. All of the equations have good explanatory power with adjusted R-squared values of 0.43 to 0.78. Model (1) states that an increase of unaided awareness of 1 percent increases the overall attitude towards energy efficiency by 0.53%. Model (2) indicates that an increase of unaided awareness of 1 percent increases knowledge of energy efficiency by 0.33%. Model (3) states that an increase of unaided awareness of 1 percent increases the attitude that the participant is an active energy conserver by 0.75%. Model (4) says that an increase of unaided awareness of 1 percent increases the attitude of planning to reduce energy consumption by 0.53%.

Table 2. Determinants of Attitudes (%)

	Overall (average three attitudes) (1)	**Knowledge of energy efficiency (2)**	**Active energy conserver (3)**	**Plan to reduce energy use (4)**
Constant	34.6*** (1.92)	50.4*** (2.48)	26.2*** (4.09)	28.3*** (2.16)
Unaided	0.53*** (0.066)	0.33*** (0.086)	0.75*** (0.14)	0.53*** (0.075)
Adjusted R^2	0.78	0.43	0.60	0.73
F	64.5 (0.00)	14.7 (0.00)	28.5 (0.00)	50.8 (0.00)

The third step in the analysis is to understand the determinants of energy behaviours. Analysis of the determinants of energy conserving behaviours is based on the regression model shown in Table 3. Column (1) models the determinants of lights off when no one is in the room. Column (2) models the determinants of minimum number of lights required to undertake the task. Column (3) models the determinants of turn television off when no one is in the room. Column (4) models the determinants of night temperature set back. Column (5) models the determinants of day temperature set back when no one is home. Column (6) models the determinants of turn water heater when no one home for three days. All of the equations have good explanatory power with adjusted R-squared values of 0.46 to 0.81. Model (1) states that an increase of composite attitude of 1 percent increases the performance of lights off when no one in room by 0.74%. Model (2) states that an increase of composite attitude of 1 percent increases performance of minimum number of lights on by 1.163%. Model (3) states that an increase of composite attitude of 1 percent increases the performance of turn television off by 1.58%. Model (4) indicates that an increase of composite attitude of 1 percent increases the performance of night temperature set back by 0.58%. Equation (5) states that an increase of composite attitude of 1 percent increases the performance of day set back by 0.92%. Equation (6) states that an increase of composite attitude of 1 percent increases performance of turn water heater off by 1.10%.

Table 3. Determinants of Behaviours (% always perform)

	Lights off no one in the room (1)	**Minimum number of lights on (2)**	**Turn television off (3)**	**Night temperature set back (4)**	**Day temperature set back (5)**	**Water heater off three days (6)**
Constant	35.4*** (5.67)	7.17 (7.33)	-9.61 (8.99)	43.5*** (7.18)	25.9** (10.3)	-26.4** (11.2)
Attitude	0.74*** (0.11)	1.16*** (0.15)	1.58*** (0.18)	0.58*** (0.14)	0.92*** (0.21)	1.10*** (0.22)
Adjusted R^2	0.70	0.77	0.81	0.46	0.51	0.56
F	42.8 (0.00)	62.9 (0.00)	77.0 (0.00)	16.2 (0.00)	19.9 (0.00)	24.0 (0.00)

The fourth step in the analysis is to estimate the impact of behaviour performance rates on energy and peak. Table 4 summarizes the results of the energy and peak savings analysis, for six energy-related behaviours.

Table 4. Determinants of Energy and Peak

Behaviour	Change in behaviour rate (%) (1)	Change in GWh per 1% change (2)	Change in MW per 1% change (3)	Energy reduction (GWh) (4)	Peak reduction (MW) (5)
Night temp setback	3.81	0.47	0.12	1.79	0.46
Day temp setback	6.04	0.30	0.08	1.81	0.48
Lights off no one in room	4.86	1.02	0.26	4.96	1.26
Use minimum lights needed	7.62	0.20	0.06	1.91	0.46
TV off if not watched	10.38	0.78	0.20	8.10	2.08
Water heater off three days	7.23	0.02	0.01	0.15	0.07
Total Impacts				18.72	4.81

Column (1) shows the results of the change in behaviour rate using Equation (2.2). Column (2) shows the change in GWh per 1% change in behaviour based on the Conservation Potential Review data. Column (3) shows the MW per 1% change in behaviour based again on the Conservation Potential review data. For each of the behaviours, column (4) provides the reduction in energy consumption, using Equation (2.3). Again, for each of these behaviours, column (5) provides the reduction in peak consumption. Impacts of the behaviour changes over F2008 and F2009 are as follows. Changes in night temperature setback saves 1.79 GWh and 0.46 MW. Changes in day temperature setback saves 1.81 GWh and 0.48 MW. Savings of 4.96 GWh and 1.26 MW can be achieved if lights are switched off when no one is in a room. Changes to use minimum lights in a room realizes savings of 1.91 GWh and 0.46 MW. Changes into turning the television off if not being used saves 8.10 GWh and 2.08 MW. Changes into turning the water heater off if residents are out of the house for three days or more saves 0.15 GWh and 0.07 MW.

Conclusions

The determinants of awareness, attitudes and behaviour were analyzed using ordinary least squares statistical modeling. Power Smart Tracker surveys and information on advertising expenditures were used to provide the database for statistical modeling. The main findings of the statistical analysis include the following.

- Awareness. An increase of cumulative advertising of 1,000 GRPS increases unaided awareness of Power Smart by 2.2%, while an increase of cumulative advertising expenditures of $1 million increase unaided awareness of Power Smart by 3.1%.

- Attitudes. An increase of unaided awareness of 1 percent increases the overall attitude towards energy efficiency by 0.53%, increases knowledge of energy efficiency by 0.33%, increases the attitude that the participant is an active energy conserver by 0.75%, and increases the attitude of planning to reduce energy consumption by 0.53%.

- Behaviours. An increase of the overall or composite attitude of 1 percent increases the performance of lights off when no one in room by 0.74%, increases performance of minimum number of lights on by 1.163%, increases the performance of turn television off by 1.58%, increases the performance of night temperature set back by 0.58%, increases the performance of day set back by 0.92%, and increases performance of turn water heater off by 1.10%.

- Energy and Peak Savings. Engineering algorithms were used to estimate the impact of behavioural change on energy and demand savings. For F2008, estimated energy savings are 9.4 GWh and estimated peak savings are 2.4 MW. For F2009, estimated energy impacts are 18.7 GWh and estimated peak impacts are 4.8 MW.

References

[1] Duke, R. and D. Kammen. *The economics of energy market transformation programs.* Energy Journal, 1999.

[2] Golove, W.H. and J.E. Eto. *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency,* Berkeley, CA: Lawrence Berkeley Laboratory, 1996.

[3] Horowitz, M. and H. Haeri. 1990. *Economic efficiency versus energy efficiency: do model conservation standards make good sense?,* Energy Economics, 1990.

[4] Jaffe, A. and R. Stavins. *Dynamic Incentives of Environmental Regulations: The Impact of Alternative Policy Instruments on Technology Diffusion,* Journal of Environmental Economics and Environment, 1995.

[5] Joskow, P. and D. Marron. 1992. *What Does a Negawatt Really Cost: Evidence From Utility Conservation Programs,* The Energy Journal, 1002.

[6] California Energy Commission. *Public Interest Energy Strategies Report.* Staff Report 100-03-012D, 2003.

[7] Janda, K., C.T. Payne, R. Kunkle and L. Lutzenhiser. *What Organizations Did (and Didn't Do): Three Factors That Shaped Conservation in California's 2001 Crisis,* Proceedings of the 2002 ACEEE Summer Study, Washington, DC: ACEEE Press Vol. 8.

[8] Lutzenhiser, L. *Social and Behavioral Aspects of Energy Use,* in Annual Review of Energy and the Environment, 1993.

[9] Stern, P.C. *Toward a Coherent Theory of Environmentally Significant Behavior,* Journal of Social Issues, 2002

[10] Sahota, R., Tiedemann, K.H, I. M. Sulyma, and J. Habart. *Behavior and Potential Energy Savings in Residential Dwellings,* Proceedings of the 2008 ACEEE Summer Study.

[11] Tiedemann, K.H, I. M. Sulyma, R. Sahota and J. Habart. *Behavior and Potential Energy Savings in Business Establishments,* Proceedings of the 2008 ACEEE Summer Study.

[12] Jackson, T. *Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change.* Centre for Environmental Strategy, University of Surrey, Guildford, Surrey, 2004.

[13] Geller, E. *Evaluating Energy Conservation Programs: Is Verbal Report Enough?,* Journal of Consumer Research, 1981.

[14] McKenzie-Mohr, D. *Promoting Sustainable Behaviour: An Introduction to Community Based Social Marketing,* Journal of Social Issues, 2002.

Energy Efficient Use Index: A Parameter for Efficient Energy Behaviour for Operating Electronic Consumer Appliances

Mercy V. Shuma-Iwisi

University of Witwatersrand, School of Electrical & Information Engineering, Johannesburg, South Africa

Abstract

A household appliance survey was conducted in Johannesburg South Africa. The survey was conducted on 555 households in eleven suburbs of the greater Johannesburg. The households in the survey formed a representative sample of households in groups 4 to 10 as defined by the Universal Living Standards Measure used in South Africa. An analysis on the household sample data resulted in 5 logical clusters of appliance penetration and saturation levels.

In the appliance ownership questionnaire, a set of questions were included on consumer appliance operational behaviour. From the analysis of these particular set of questions it was possible to extract a new variable named Energy Efficient Use Index. The index attains values between 0 and 1. The index is introduced in the appliance energy consumption equation to determine the final energy consumption levels. A high index, results in high consumption levels whilst a lower index results in low energy consumption levels. Thus a lower index levels is commensurate with better appliance use behaviour as far as energy efficiency is concerned. The index was found to be high in clusters with high appliance saturation and penetration levels and low in clusters with low appliance saturation and penetration rates. This confirmed the link between energy efficient behaviour and appliance ownership levels.

1. Introduction

Over the years there has been evidence of the growing electricity consumption in the residential sectors in many countries around the world. Consumer electronics and information & communication equipment has been identified as the fastest growing electricity end-use in the residential sector in the Enlarged European Union region [1]. There has been a growing need to implement measures that will result in sustainable electricity consumption in households if a worldwide energy crisis is to be averted [1] [2] [3]. Sustainable electricity consumption is on one hand the action of actively and continuously choosing renewable or other less environmentally harmful electricity sources. On the other hand it is the conscious choice of appliances that one purchases, as well as the duration that one runs the appliances in different modes of operation with the ultimate goal of reducing the total energy consumption [4]. This implies active human interaction with the appliances which results in different energy consumption levels in the industrial, commercial and domestic sectors [5].

Household energy use is driven by energy-related behaviors' and these are found in three main activities namely: purchase of new appliances/equipment, usage of the appliances in the household and in maintenance of the appliances [6]. Usage behavior is the day to day usage decisions made in operating the appliances in the household.

Energy consumption is said to have two components of which one is driven by human behavior and the other is baseline energy consumption [5]. Human driven energy is basically the energy usage due to individuals' use of appliances and equipment. Baseline energy consumption is defined to be the minimum energy that is consumed at an occupied household or office. In households the baseline energy is due to standby power, home security systems, centrally controlled space heating systems, refrigeration and Information Technology (IT) equipment.

Human involvement complicates the estimation of electricity consumption in households. This is because of the different operational decisions of each individual member within a specific household on how they personally interact with the appliances. Therefore, human driven energy use is the most varying and most unpredictable element in appliance energy consumption [5]. It has been determined that up to 26% of household energy consumption can be attributed to user behavior [6].

Normally when individuals operate appliances they do not directly engage with the energy consumption levels in the appliance due to their operational decisions. The operator becomes oblivious of the amount of energy being consumed by the appliance due to their operational decisions. The resulting energy consumption levels are far removed from the operator and therefore have no impact on their operational behavior. Therefore consumers do not know the energy cost due to their operational behaviors pertaining to their direct interactions with appliances. This highlights the importance of a carefully designed human-appliance interface that results in inherent energy conservation as well as immediate feedback on energy consumption [6] [7].

Standby power is human-driven energy consumption because it depends on the state in which the appliance is left in when not in use [7]. The operator of an appliance determines the state of the appliance when not in use. Appliances with standby power capabilities can [7]:

- Be a remote controlled or non-remote controlled appliance
- Have a power off switch that when activated results in 'soft off' or 'hard off' state. A soft off state is defined as the state in which an appliance when switched off at the appliance power switch it continues to consume very small amounts of power. The power consumed in 'soft off' state is normally less than the power consumed in standby mode. An appliance is in the 'hard off' state if when switched off at the appliance power switch it does not consume power.
- Have no power off switch

Of these options, the remote control is a common operator/appliance interface found in many consumer electronic appliances. If an operator switches off an appliance using a remote control it is automatically left in standby mode and results in standby energy losses. On the other hand if the same operator instead decides to switch off the appliance at the wall switch then the appliance is in the off state and there are no standby energy losses. The user operational behavior determines the end the state in which the appliance is left in when not in use. Therefore, ownership of appliances with standby power capabilities only indicates a possibility of households to contribute to standby energy losses. The individual household member's operational behaviors are the absolute determinants of the presence of standby energy losses in the household [7].

In most work involving quantification of appliance standby power energy losses in a household the parameters used are [7]: Appliance saturation and penetration rates, time of use, and appliance standby power level. The assumption is that ownership of appliances with standby power capabilities implies standby energy losses. The weight of the decision of the operator on how to switch off the appliance is not taken into consideration. In this paper we argue that there is a need to add a fourth parameter for operational behavior because:

- The state of the appliance when not in use is what finally determines if an appliance contributes to standby energy losses
- The operational behavior determines the appliance end state
- Standby power is behavior driven energy consumption

This paper investigates how operational behavior i.e. an individual's engagement with the appliance can be quantitatively measured. The methodology is discussed in section 2, and the results are presented in section 3. Discussion of the results is presented in section 4, and the recommendations and conclusions are in section 5.

2. Survey Methodology

A survey was conducted on 555 households in eleven suburbs of the greater Johannesburg Metropolitan. The numbers of households surveyed in each suburb are presented in Table 1 [7]. A section of the survey had questions designed to establish how consumers operated their appliances. This was done to ascertain if the appliance operational behavior lend itself to standby energy losses. The questions covered two separate groups of appliances namely remote controlled appliances and non-remote controlled appliances. The remote controlled appliances covered are: television sets, digital satellite decoders, DVD's, Hi-Fi's and VCR's. The non-remote controlled appliances are:

personal computers, monitors, microwave ovens, mobile phone battery chargers (MPBC), printers, and printers/fax/copiers) (Multifunction devices).

Table 1: Surveyed Households [7]

Suburb Name	Number of Households
Devland	36
Lenasia Extension 1	126
Lenasia Extension 3	72
Lenasia Extension 7	46
Lenasia Extension 8	61
Florida	76
Florida Park	30
Gressworld	18
Kew	28
Waverly	30
Alexandra East Bank (AEB)	32

The questions for remote controlled appliances read:

When not in use the following appliances are normally:

- *Switched off with the remote controller (RC)*
- *Switched off at the appliance power switch (PS)*
- *Switched off at the wall switch (WS)*

With regard to non-remote controlled appliances the question read:

When not in use the following appliances are normally:

- *Left on all the time (LO)*
- *Switched on only when required for use (SU)*

From a measurement campaign conducted in 30 representative households among the 555 in which the survey was conducted, the two switch off states of ‘soft off’ and hard off’ were recorded for each appliance measured. This was done to ascertain the presence of appliances with these switch off states in the households. The results are presented in Table 2. From table 2 it is evident that over the years the user/appliance interface has gradually changed to a point where it is no longer possible to completely switch off an appliance. This can also be explained by the presence of intelligent devices that maintain minimum functionality in most household electronic appliances.

3. Results

The results for remote controlled and non-remote controlled appliances are presented for each suburb.

3.1 Remote Controlled Appliances

In remote controlled appliances the action RC and PS results in an appliance in standby mode because most of the appliances do not have a ‘soft off’ state. This is because the number of remote controlled appliances found to have a ‘soft off’ capability during the measurement campaign as seen in table 2 [7] was negligible. Mostly, the ‘soft off’ capability was found in very old models and therefore considered insignificant as indicated in table 2 [7].

Table 2: Remote Controlled Appliances with ‘Soft Off” Mode [7]

Appliance	# of Appliances With Soft Off	Total # of Measured Appliances
Television	3	145
VCR	0	49
DVD	1	84
Hi-Fi	0	40
Mini Hi-Fi	2	37
Satellite Decoder	0	36

Table 3 presents the number of RC and PS responses for remote controlled appliances in each suburb**.** The total numbers in table 3 reflect the number of respondents that exhibit an operational behavior that results in the standby state for each appliance. The percentage value for each appliance represents the percentage of respondents whose operational behavior results in standby energy losses. The extent of the contribution of each appliance category to standby power and energy losses is limited to the numbers that are left in standby mode. The user operational behavior directly determines the numbers of appliances left in standby state when not in use.

Table 3: RC and PS Responses

		Remote controlled Appliances				
Suburb	**Total number of respondents**	**TV**	**VCR**	**DVD**	**HIFI**	**Satellite Decoder**
Devland	36	28	24	30	36	36
Lenasia Ext. 8	61	56	51	51	48	58
Gressworld	18	14	12	14	17	18
Alexandra East Bank	32	32	29	30	32	32
Lenasia Ext. 1	126	108	106	105	110	117
Lenasia Ext.3	72	60	57	62	58	71
Kew	28	26	25	24	24	28
Florida	76	68	64	71	72	75
Florida Park	30	27	26	25	29	30
Lenasia Ext.7	46	45	44	44	40	44
Waverly	30	29	29	29	29	30
Total	555	493	467	485	495	539
Percentage		**88.8**	**84.1**	**87.4**	**89.2**	**97.1**

As seen in table 3, the satellite decoder is the appliance in which six suburbs have 100% response implying that all satellite decoders in these six suburbs contribute to standby energy losses. Also, satellite decoder's present the highest percentage of 97.1 when compared to the other appliances in table 3. These two occurrences can be attributed to the service provider instructions to clients that the decoders should always be left in standby mode to allow for software downloads to the decoders. The impact of service provider instructions and other manufacturers default settings on appliances in shaping the operational behavior of the appliance users is demonstrated for satellite decoders as seen in table 3.

The complement of each percentage entry in Table 3 represents the percentage of appliances that are switched off at the wall resulting in a 'hard off' state and zero standby energy losses. The figures are low suggesting that for remote controlled appliances, the user operational behavior in most household's results in standby energy losses. This demonstrates the impact of the appliance /user interface in shaping the operational behavior of appliance users. However, one cannot discount the few households in which the operational behavior does not result in standby energy losses.

The whole purpose of energy efficiency awareness campaigns and consumer education is to decrease the percentages of appliances left in standby mode. Therefore a positive behavioral change would result in the decrease in percentages for each appliance presented in table 3. The decrease can be used as a measure of change in appliance operational behavior after an awareness campaign but it is important to establish a point of reference before the campaign is implemented.

3.2 Non-Remote Controlled Appliances

For non remote controlled appliances the two responses are *Left On All the Time (LO)* and *Switched on When Required for use (SU)*. Table 4 presents the results for the response LO for the different appliances in each of the eleven suburbs as well as the sample percentage response for each appliance.

Table 4: LO Response for Non Remote Controlled Appliances

		Non-Remote controlled Appliances					
Suburb	**Total number of respondents**	**PC/ Monitor**	**MFD**	**Printer**	**Fax**	**MWO**	**MPBC**
Devland	36	8	0	0	36	13	6
Lenasia Ext. 8	61	9	41	26	31	35	16
Gressworld	18	11	0	11	18	14	5
Alexandra East Bank	32	7	16	14	16	24	7
Lenasia Ext. 1	126	21	42	15	39	79	28
Lenasia Ext.3	72	18	36	23	43	35	12
Kew	28	8	28	6	20	22	6
Florida	76	25	70	42	57	63	27
Florida Park	30	10	26	10	30	27	9
Lenasia Ext.7	46	9	29	9	0	38	9
Waverly	30	6	22	18	19	29	19
Total	555	132	310	174	309	379	144
Percentage		**23.8**	**61.9**	**33.5**	**55.7**	**68.3**	25.9

PC: Personal computer; MFD: Multi function device; MWO: Microwave oven;

MPBC: Mobile phone battery charger

In table 4, cells with 0 entries imply that the particular appliance was not found in any of the households in the corresponding suburbs. From table 4 it is evident that PC/monitors and mobile phone battery chargers have lowest responses across all suburbs as well as the lowest sample percentages. This indicates that in the majority of the households in the sample, these appliances do not contribute to standby energy losses. The user operational behavior directly determines the state of these appliances when not in use. From the low percentages observed for personal computers/monitors and mobile phone battery chargers it can be said that most of the respondents in the sample exhibit energy efficient appliance operational behavior with respect to these two appliances.

Multifunction devices (MFD) come with a fax capability and like the fax machine; these two appliances have to be left on since the user does not have control of when a fax is received. Therefore the functionality of the appliances directly affects the user operational behavior and as it evident from table 4 the sample percentages support this argument. The microwave oven sample percentage is 68.3%. This can be attributed to the high usage rate of the appliance in a household necessitating that the appliance be left on all the time. The complements of the numbers in table 4 represent the responses in each suburb and sample percentages indicating that the appliances are switched on only when required for use.

The results obtained further underscores the argument that ownership of an appliance does not necessarily imply that the appliance contributes to standby energy losses because standby energy losses are determined by the state of the appliance when not in use and this solely depends on operational behavior of the user.

It must be said that Johannesburg is one of the areas in South Africa where high lightning strikes are recorded [8]. Households therefore, do have a tendency to disconnect appliances from the wall outlet to avoid damage from lightning. It can also be observed that in Devland prepaid meters are installed in all households. Direct feedback from prepaid meters raises the concern of the household members on the electricity losses incurred when members are away from home. The low percentage rates noted for Devland across all appliances both remote and non-remote controlled appliances can be attributed to direct feedback.

4. Discussion of the Results

From the results in tables 3 and 4 we can determine the Appliance Efficient Use Index (AEUI) of each appliance for the household sample. The term AEUI is the measure of energy efficiency behavior exhibited by the household sample in appliance operation [7]. Values of AEUI are defined between the range of 0 and 1. A measure of 1 indicates total inefficient operational behavior while a measure of 0 indicates best operational behavior.

AEUI is the percentages obtained for the two scenarios in table 3 and 4 expressed as a fraction. Therefore 100% response indicates AEUI = 1 implying that all the appliances are in standby mode when not in use. A result of 0% indicates an AEUI = 0 implying none of the appliances are left in standby mode when not in use and therefore standby energy losses due to such appliances are zero. All other indices between 0 and 1 indicate that only a fraction of appliances contribute to standby power losses as a result of the final operational mode when not in use.

Table 5 present the AEUI for the remote controlled and non-remote controlled appliances for the household sample. The AEUI is used to determine the number of appliances that contribute to standby energy losses. The number of appliances contributing to standby energy losses is a product of the saturation levels, penetration levels and the AEUI index. In all cases except where the AEUI value is 1 the total number of appliances contributing to standby energy losses is less than the number of appliances installed in the households.

From table 5, it is seen that the AEUI indices for remote controlled appliances are higher than for non-remote controlled appliances. This attests to the importance of the appliance/operator interface because the availability of the remote controller shapes the operator behavior switching off the appliance using the remote controller resulting appliances in standby mode when not in use.

Table 5: AEUI for Remote and Non-remote Controlled Appliances

	Remote controlled						Non-Remote Controlled					
Appliance	TV	VCR	DVD	HIFI	Satellite Decoder		PC/ Monitor	MFD	Printer	Fax	MWO	MPBC
Percentage	88.8	84.1	87.4	89.2	97.1		23.8	61.9	33.5	55.7	68.3	25.9
AEUI	0.89	0.84	0.87	0.89	0.97		0.24	0.62	0.34	0.56	0.68	0.26

MFD: Multifunction device; MWO: Microwave oven; MPBC: Mobile phone battery charger

The AEUI of non-remote controlled appliances are generally much lower compared to those of remote controlled appliances as can be seen in table 5. The AEUI values for non-remote controlled appliances can be attributed to frequency of use of the appliances. Low usage rate can be said to be true for PC/Monitors and printers. Low usage rate can influence the user behavior into switching the appliance off when not in use because of the long amount of time that the appliance is not in use. However the opposite is also true. i.e. high usage rates can influence the user to leave the appliance on all the time. This is the case of microwave ovens (MWO) as seen in table 5.

Secondly the function of the appliance can also influence the behavior of the user. This is the case of multifunction devices (MFD) and fax machines and is due to the fact that the fax function necessitates that the machine be left on all the time. This results in the much higher AEUI values for MFD and fax machines when compared to the other non-remote controlled appliances.

The AEUI values for each appliance for the sample used can be said to be directly influenced by:

- The appliance/operator interface (remote controller)
- Direct energy consumption feedback to households (prepaid meters)
- Presence of other considerations such as not replacing units damaged by lightning strikes
- Appliance usage rate

The high occurrences of lightning in the area where the research was done could also account for appliances being switched off when not in use.

The significance of AEUI values for each appliance is in the determination of the total number of appliances that contribute to standby energy losses. The number of appliances in standby mode is the product of the number of appliances installed in the households and the corresponding AEUI value for the appliance. For example from table 5 it can be deduced that the fraction of the total appliances contributing to standby energy losses in the household sample is: 0.97 for satellite decoders and only 0.24 for PC/monitors.

The findings of this work apply only to a single operator. Normally in a household there are multiple operators but where there is an interface like the case of a remote controller or where the appliance usage rates argument apply the results are expected to be the same irrespective of the operator. However, where the appliance switch off capabilities allow for different switch off states then it is possible that different operators would operate the appliance differently resulting in different power consuming levels for a appliance when not in use. This calls for careful design of the appliance/operator interfaces of all appliances to recognize the importance of the interface to energy losses.

5. Conclusion

Standby energy losses are driven by appliance operational behavior. Ownership of an appliance with standby energy losses capability does not guarantee that the appliance contributes to standby energy losses. An appliance contributes to standby power losses only if it is left in standby mode when not in use. Appliance Energy Efficient Use Index (AEUI) is a parameter that has been introduced as measure of the appliance operational behavior of individuals in operating different appliances in a sample of households. The appliances fall into two broad categories of remote controlled and non-remote controlled appliances. The AEUI values for each appliance range between 0 and 1. A value of 1 implies none of the individuals exhibits energy efficient behavior in operating that particular appliance, while a value of 0 implies all the individuals' exhibit energy efficient behavior in operating the appliances. A none zero AEUI value for a particular appliance implies that only a fraction of all the appliances found in the household sample contribute to standby energy losses. The fraction is determined by the AEUI value.

From the research conducted it is argued that the operational behavior is directly linked to the AEUI of a particular appliance. The operational behavior is argued to be directly affected by the:

- Appliance/operator interface
- Appliance usage rate
- Function of the appliance
- Climatic factors (high lightning occurrences)
- Direct feedback from prepaid meters

A household is a made up of a collection of individuals and therefore there is a need to carefully consider the effect of multi-operators in determining the values of AEUI.

6. References

[1] Bertoldi P., and Atanasiu B, Electricity Consumption and Efficiency Trends in Enlarged European Union, Status Report 2006, Institute for Environment & Sustainability, 2007 EUR 22753 EN

[2] Roth K. Residential Information Technology Energy Consumption in the USA, Proceedings of 4th International Conference on Energy Efficiency in Domestic Appliances & Lighting , 21-23 June 2006, London United Kingdom.

[3] Harrington L., Kleverlaan P. Quantification of Residential Standby Power in Australia: Results of Recent Survey, Final Report , National Appliance & Equipment Energy Efficient Committee, April 2001

[4] Fischer C, Energy Efficiency, May 2008, pp 79-104, Springer Science & Business Media B.V, 2008

[5] Taherian S, Marcelo P, Coulouris G, and Crowcroft J, Profiling Energy Use in Households and Office Spaces, e-Energy '10 April 13-15, 2010, Passau Germany

[6] Van Raaij W. , Verhallen T. M. M., A Behavioral Model of Residential Energy Use, Journal of Economic Psychology 3 pp 39-63, November 1982.

[7] Shuma-Iwisi M. V., Estimation of Standby Power and Energy Losses in South African Homes, PhD, Thesis University of Witwatersrand November 2009.

[8] De Wet P., How to Deal with a Million Bolts a Month, http://mg.co.za/printformat/single/2011_01_28_how_to_deal_with_a_million_bolts_month/ Last accessed on Monday 9th May 2011

.

Expanding Adoption of Residential Energy Efficiency Projects: A Focus on Behavioral Change, Funding & Partnerships

Melissa M Downes
Harvard University, Sustainability & Environmental Management Teaching Fellow

ABSTRACT

Climate change mitigation strategies have been characterized by 15 wedges with increased heating efficiency being one wedge. Residential energy conservation and efficiency projects are feasible in terms of technology, and utility bill savings far exceed the costs. However, American households have not embraced associated home improvement projects. In order to understand this resistance a literature search examined benefit classifications of goods and services, alternative finance organizations, and psychological factors with social networks. Interviews were conducted to validate challenges and opportunities as well as explore possible future initiatives or tool development.

The importance of psychology is to motivate individuals by utilizing language that stresses a future vision rather than a technical education. The focus was for recommendations that are both scalable and expandable thereby facilitating significant greenhouse gas reductions. A network model was developed including utilization of organizations with two emerging options. One is for employers to enable employees to undertake home improvements either through an employer-based credit union or partnerships with energy service providers. A second model for seasoned organizations to commit to development of training seminars and best practices for other building professionals with a focus on skills required to ascend the learning curves for Leadership in Energy and Environmental Design (LEED) buildings and other sustainability practices.

Introduction

Residential energy efficiency, like personal computers, began in the 1970s but today does not enjoy the same adoption successes. Hence the following question: *"Why are so few home owners willing to undertake energy efficiency to make homes more comfortable and economical?"* One possible explanation is that energy efficiency requires both awareness and time to implement and is therefore competing with peoples' other high priority items. Another possible explanation is the absence of an effective business model.

Imagine a future reality where there is a known and effective business model for the implementation of residential energy efficiency projects. This business model is repeatable and scalable from an individual house, to a neighborhood, to a city and to the state level. The components are comprehensive, centralized, and streamlined with a process that is transparent and verifiable to homeowners. Moreover, the breadth of the model would include funding, energy assessments and scores, approved and validated implementation solutions, and post commissioning services such as performance guarantees. The options available to homeowners would include efficient appliances and lighting, heating systems, and improvements to the building envelope such as insulation and windows. In this vision homeowners would have various motivations—savings on utility bills, improving comfort, increasing resale value, reducing their carbon footprint, or all of the above. In this reality, completed energy efficiency projects would penetrate over 85% of the residential building stock.

Behind every inspirational vision is a series of goals tied together by a group of frameworks, policies and models. Energy efficiency policy is only one component in the broader climate change mitigation framework. Addressing residential use is only one focus in the broader goal of transforming our energy sector. Therefore, the challenge is to find an energy efficiency model that embraces what currently works and limit changes to deficiencies or what is missing altogether.

This paper will review several aspects of creating a comprehensive organizational model and is organized as follows: The first section is the background covering the current state of energy efficiency, and a foundation of broader economic, ethical and psychology principles that are applicable to increasing residential energy efficiency programs. The second section reviews two potential leverage points for organizations to utilize - social marketing and funding. The third section has the results discussion and the necessary components for an integrated solution. The fourth section concludes with a series of recommendations ranging from high level policy to specific features.

Background: A multi-discipline approach

There is a broad array of initiatives being undertaken in an effort to increase adoption of residential energy efficiency or conservation. Interested stakeholders of these initiatives include citizens, advocacy groups, environmental activists, businesses, and various levels of government. Furthermore, these initiatives encompass a diverse range of project scales. For example, energy efficiency programs can be as small as an individual household, to an entire university campus, to a regional utility company offering rebates or to a national funding effort such as the American Recovery and Reinvestment Act of 2009. Evidence to date suggests the optimal modus of operation requires a method for systematic adoption of best practices across the largest group of stakeholders. This method needs to be sufficiently flexible to incorporate new lessons learned from previous projects and to be adaptable for specific community challenges.

"Driving Demand", a comprehensive review published by the Berkeley National Laboratories, discusses 14 existing programs and examines their effectiveness to inform and persuade homeowners. These programs have an array of goals (assistance to low income homes or alternative solutions to increasing utilities infrastructure) and strategies (nature of incentives, financing and outreach methods). Berkeley National Laboratory states that there needs to be a plan in place from the start in order to gather useful metrics for modifying a program and tracking its long term efficacy [1] . For the reviewed programs, a variety of metrics were provided that included percent upgraded per year and average savings as well as direct and overhead costs. The most successful programs achieved a 36 to 92% upgrade of all eligible homes and individual energy savings ranged from 12 to 17% [1]. However, when you look at programs that have been running for three years or longer and have involved some costs to the homeowner—the percentage of upgraded homes per year drops to below 10% [1].

This lower participation rate is consistent with conclusions from other studies. One study reached out to 800 Nebraskans (USA) and found the most common constraints were (1) financial in terms of either discounts on upfront costs or financing; (2) need additional information; (3) need professional assistance; (4) needed more time to do it yourself. Even more importantly, the author concluded that focusing on individuals predisposed to energy conservation and removing constraints could be more productive than educators attempting to change attitudes [2]. Another online survey of 505 people found that the general public had misconceptions surrounding energy consumption and savings. The two commonly held inaccuracies were that

(1) Energy conservation is more effective than energy efficiency; and

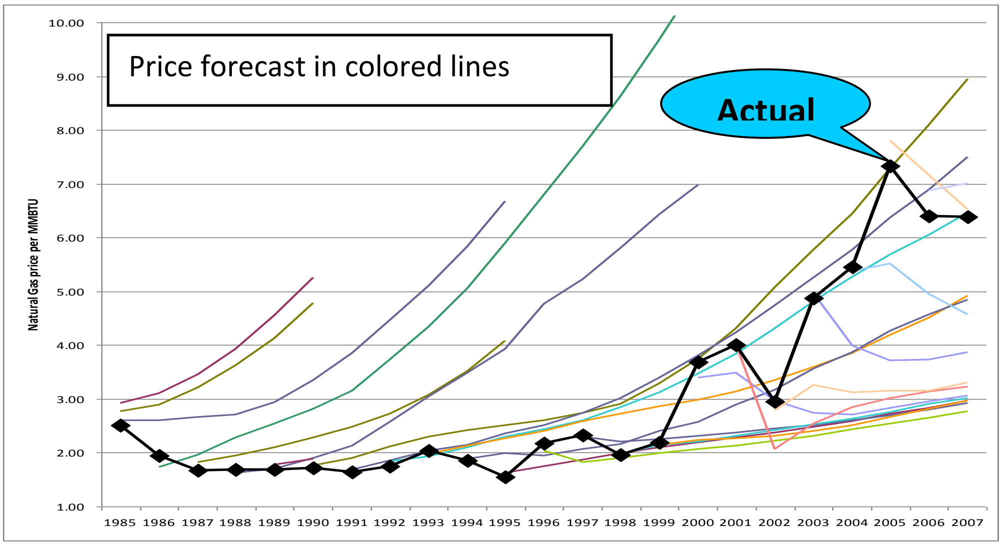
(2) After a correct identification of the most energy efficient device from a pair of comparable items, e.g. laptop vs. desktop, participants' demonstrated poor accuracy regarding the potential amount of energy savings. [3].

As the authors state: "In other words, people's understanding may be worse where the potential for carbon dioxide (CO_2) reductions is large, although other considerations such as how often a device is used over the course of a year are also relevant [3]." These findings high light the continued need for public service messages to address these misconceptions.

Both studies discuss the value of behavioral change as part of the solution to increasing adoption of residential energy efficiency. These studies help explain a third finding—that economic metrics are not sufficient to predict adoption of energy conservation [4]. A number of behavioral factors including procrastination and avoiding short term inconvenience can have a larger impact than the economic realities [4]. It is important to create a product or service with quick turnaround to ensure a high percent move through the process to complete their home upgrades. The consensus is that effective energy efficiency program requires a comprehensive plan that addresses how to get homeowners to "yes".

One variable in developing a comprehensive plan is the cost effectiveness of a project which is tied to the prevailing cost of energy. While there is consensus that fossil fuel prices are likely to rise, the track record in predicting actual prices is unreliable as shown in Figure 1 below [5] . Furthermore, even in the last 40 years there have been periods of decreasing energy costs. As a direct consequence, there is uncertainty of the cost-benefits for energy efficiency solutions where the breakeven point is expected to be more than several years. This variability should be considered when trying to determine if residential energy efficiency organizations will pursue a nonprofit or private business model. Although it is worth noting to date cost-benefit information has been insufficient as a motivator for homeowners and there is a growing consensus that behavioral interventions need to be considered [4]. On an encouraging note, the cost of psychological nudges can be more effective as well as more economical than price changes [4].

Figure 1: PREDICTED VS. ACTUAL ENERGY PRICES – 1985 to 2007



Source: Giudice, Paul. “Renewable Energy's Future in New England”. Speech at the Restructuring Roundtable. Boston, MA. Sept. 17, 2010.; Originally from USA EIA (2009)

However Allcott is advocating for more rigor in research such as the scientific method used by the natural sciences, so that policy makers can understand what information gaps exist and to expand cost-benefit knowledge. The cost-benefit information is currently lacking. To date most residential energy efficiency efforts have been funded based on activity (energy assessment or change in equipment) rather than verification of saved energy. Since upfront costs are a large concern for homeowners, this focus is understandable. However, to take the additional step and monitor homes’ utility bills is essential to provide feedback on what really is effective for future initiatives. The monitoring of energy efficiency efforts have several benefits such as (1) motivating homeowners with known paybacks, (2) accountability and transparency for taxpayers in cases of government funding, and (3) ability to determine if aggregate energy savings on a regional, national, or continental basis are significant. The necessity of reaching significant savings on a global scale is important because energy savings are a proxy for carbon and emission reductions. This is why a systematic approach with broad repeatability—participants and deployed solutions—to reduce carbon emissions is essential. Energy efficiency has the ability to meet these criteria and has been identified as one possible strategy for addressing the broader issue of climate change mitigation.

The wedge strategy (see side panel) consists of 15 climate change mitigation strategies that are comprehensive and feasible for implementation now [6]. The following mitigation strategies incorporate various options specific to energy use:

- Incentives for energy efficiency and conservation
- Renewable and biostorage
- Fuel switching

The deployment of existing energy efficient technologies is the near term and lowest cost option for moderating our nation's demand for energy especially over the next decade [7]. While other initiatives are about new processes focused on building capabilities to support wedge strategies. Examples of these include social investing, clear accounting standards, and community-based social marketing that motivate individual behavioral change through community ties.

All of theses efforts need to be measured and combined on an international basis. The effectiveness of aggregate greenhouse gas (GHG) emission reductions have to be measured in relationship to the atmosphere and overall climate system. Furthermore, carbon has the unfortunate dual distinction of large volumes and long residency in the atmosphere. While carbon is the most referenced gas in these discussions, there is actually a lengthy list of GHG which can be converted to carbon dioxide (CO_2) equivalents and therefore rolled up into a single aggregate number. The gases being converted to CO_2 equivalencies can generally be characterized as smaller in volume but much more potent and there by relevant to the development of effective climate mitigation strategies.

<u>The 15 Wedges</u>

The wedge is a reference to a frequently cited graph showing the potential difference in greenhouse gas (GHG) reductions between two possible scenarios and the difference looks similar to a triangle. This triangle is shown in green in Figure 1 and was subdivided into smaller slices or wedges to represent 15 strategies necessary to reduce GHG. Each of these wedges would result in significant reductions if a strategy was widely implemented. Energy efficiency including buildings is one of the 15 strategies or wedges.

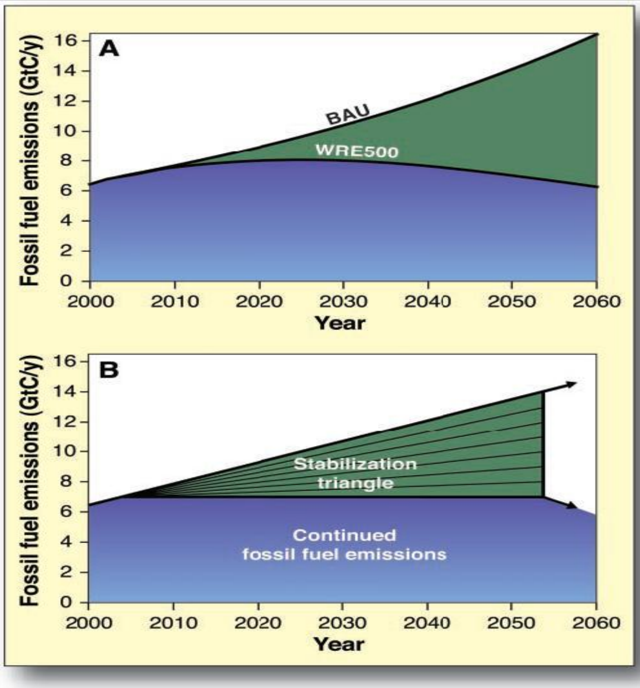


Fig. 1: Visual Representation of 2 possible courses for the future of CO_2 emissions. (A) The Business As Usual (BAU) curve represents no behavioral changes and the WRE500 represents peak CO_2 emissions of 500 part per million. (B) The green area is altered to represent a sliced triangular area with each slice representing a potential strategy for GHG reductions [6].

Climate change mitigation is not dissimilar from the clean water and air issues addressed by previous environmental policies. Like water and air, one group can benefit from the use of these resources while negative impacts (such as pollution) are borne by a different group or society at large. Moreover, air and water systems tend to be independent of state and national borders. As a result climate mitigation requires national and international coordination when considering impacted communities. For example, the Colorado River starts in the USA but ends in Mexico and international treaties are in place regarding annual cubic feet quantities reach Mexico [8].

Furthermore, carbon represents a public good because everyone benefits if the current levels of GHG in the atmosphere were to stabilize at pre-industrial levels [9]. This benefit is global in nature irrespective of who actually reduced their emissions and is susceptible to the "tragedy of the commons" problem. The "tragedy of the commons" also referred to as a "free rider" problem—e.g. when one individual invests in a shared resource, but everyone can use and benefit from the resource [9]. Originally the shared resource was a field (commons) for livestock grazing. Tragedy referred to the potential for overgrazing from an increasing number of livestock because individuals had no incentives to restrict livestock populations [10]. Energy efficiency creates a shared resource in reduced carbon emissions that has the potential to benefit everyone. The costs and primary benefits such as lower utility bills goes to an individual or organization but secondary benefits of reduced emissions are also shared with the broader community. In other words, energy efficiency is a blend of private and public benefit classifications. This clarification is relevant to decisions surrounding whether the costs should be privately or publicly funded.

Understanding benefit classifications is relevant to developing a business model for residential energy efficiency. There are four benefit classifications - private, public, group and trade benefit [11]. First, it is helpful to distinguish between private and public benefit types. In general public benefits are recognized as being beneficial to an individual first and to the broader community or society second. As an example, a book store provides a private benefit while a town library provides a public benefit. It is possible to leave with a book from both, but the library owns and lends the patron a book which is funded from the municipality's tax base. The library permits citizens to enjoy reading books without having to pay for a book or an entire collection. The affordability of access to the collection is a part of the value being provided. In other words the enjoyment from owning the book is restricted to the paying customer (private benefit) while multiple patrons would enjoy reading the town's library book (public benefit of increased education). The use of combined private and public benefit for nonprofit fund raising has already proven to be effective. For example, the Public Broadcasting System (PBS) has a program where donors receive a membership card that provides discounts for other goods and services.

The remaining two benefits are referred to as group and trade benefits. Like the public benefit, group and trade benefits are particularly relevant to nonprofit groups. The group benefit is defined as being funded by donors who are interested in helping a beneficiary subgroup. The group benefit applies to a donor population that is not sufficiently large (relative to the general public) to be supported by government based funding.

The trade benefit is where nonprofit groups receive resources from other institutions or groups which have a corresponding mission or interest with the nonprofit. Trade benefit can be of significant value to nonprofits and should be viewed as a win-win. For a corporation using trade benefit, the philanthropic activity can be strategically linked to public recognition as part of their strategy to build visibility and goodwill with customers. Any product or service can be associated with multiple benefit classifications and are accessible to any organization. However, private and trade benefit categories can be accounted for as market transactions and are the primary focus within the private sector. In contrast, the group and public benefits tend to be concentrated in government or nonprofit sectors.

The benefit classification is important in the context of how energy efficiency organizations will market their services. An understanding of who benefits from a product is basic to any marketing strategy. Since energy efficiency is a mix of private and public benefit the marketing strategy should leverage the benefits to the homeowner and their community. In a relatively low cost energy economy (MA relative to Europe), the financial savings alone are not sufficient to motivate middle class homeowners. Currently utility companies' communications with homeowners include the link between reduced utility bills and reduced environmental impact; and providing energy assessments with suggested home improvements. Unfortunately these efforts are being undermined by a weak ability to motivate home owners into taking action. This weakness can be attributed to organizations not leveraging psychological factors to create a value proposition that speaks to normative behavior (social constraints) of the greater community. Another weakness is a reliance on credits or subsidies for projects which has retarded the development of metrics to prove energy savings to homeowners. The ability to prove energy savings could be utilized as a powerful motivator and lead to a profitable business model without government subsidies.

An understanding of how psychological factors can be used to motivate citizens to consider non-financial benefits of energy efficiency is important. Marketing strategies linking individual and community benefits of residential energy efficiency is necessary to overcome individuals' inertia. By beginning with individual behavior change, it is possible to create a new paradigm to benefit both the individual and community. Prior to discussing the individual behavior change, a broader discussion on psychological theory will set the stage.

Abraham Maslow's theory provides a framework to understanding the priority of individuals' needs in the context of changing economic fortunes. Maslow's theory of "hierarchy of needs" for individuals is represented by a pyramid which has the essential or lowest needs first and then moves progressively through a series of higher needs [12]. The pyramid starts with basic material values or needs which are recognized as survival elements for life e.g. food, shelter, and security. Once basic values have been met, then individuals begin to express higher needs including esteem, belonging, and self creation. Today this second group of needs is referred to as "post material" or "fulfillment values" [12]. This concept of hierarchy of needs is one psychological theory for understanding how organizations can motivate individuals.

Another role of psychology in promoting sustainability was reviewed in *Influencing the Individual to Effect Behavior at a Broader Societal Leve*l. The research found: "assessed websites are failing to address the most important psychological factors….determined as extremely influential in getting people to adopt…sustainable behavior"[13]. As part of the study, a framework was created utilizing eight variables to evaluate 20 websites focused on climate change. The findings concluded that there is significant opportunity to increase the effectiveness of websites to motivate sustainable behavior.

Psychological factors are one way to understand how to influence behavior. However, the use of moral persuasion was not found in and of itself to be sufficient for altering behavior. In contrast, several psychological factors are relevant for organizations to better understand individual/consumer behavior thereby improving the effectiveness of their outreach and website messages. The three strongest factors identified were (1) knowledge of action strategies, (2) locus of control, and (3) attitudes [15]. In other words, a website that was able to offer specific, actionable solutions that would benefit the individual while demonstrating value to the greater community have an increased success in generating sustainable behavioral changes.

Leverage Points

Social Marketing

Social marketing creates behavioral changes by utilizing psychological factors. The evaluation of organizations using social marketing was restricted to evaluation of websites' application and their use of the psychological factors. The process was focused on content of the messages. While this could be considered a limitation, surveyed program managers stated that given the current popularity of websites they would have increased their online efforts [1]. These psychological factors (Table 1 below) are helpful when trying to implement energy efficiency initiatives that involve motivating individuals with non-financial criteria.

Table I: Psychological Factors and Applied Website Criteria

Factors	**Website Criteria - (**Must satisfy all points**)**
Knowledge About Primary Mission	• Provide information about the causes & impacts of climate change? • Identify the urgency & magnitude of action needed to mitigate climate change?
Knowledge About Sustainable Solutions	• Provide Information on specific solutions or actions to adopt? • Information clearly details level of environmental impact? • Information about specific products and where to purchase them?
Attitudes	• Encourage people to have a positive attitude towards climate change mitigation? • Suggest will be better off personally as a result of reducing their carbon footprint?
Motives	• Appeal to hedonic, gain and normative goals? • Attempt to understand who the user is?
Locus Of Control	• Increase peoples' locus of control by showing them that their action matter & how? • Link users so they can see others progress? • Provide an individual and collective carbon calculator?
Social Norms	• Promote sustainability as the social norm? • Engage people in their everyday lives & online? • Mechanism of recognition on line?
Goals	• Clear individual goal and a timeline? • Provide a community goal?
Feedback	• Continuous feedback on the user's performance?

Source: Johnston G, *"Influencing the Individual to Effect Behavior at a Broader Societal Level".* Capstone Project: Harvard University, ALM in Sustainable & Environmental Management, 2009.

In terms of motivating individuals to make change, three factors were found to be most effective. The first key factor is knowledge about sustainable solutions and represents the call to action. Organizations seem to understand what information they want to communicate to their target audience. The second important factor utilized is locus of control, which requires showing individual performance and comparing it against other individuals in the broader community. When communicating the benefit of an action, organizations need to demonstrate the impact if everyone participates. For example, charities have successfully raised large donations with walk or run events where individuals get donations based on mileage.

The third key factor is positive attitude and refers to people's need to be inspired with a broader vision. For example: "Today is an exciting moment; we have the ability to wipe out suffering and death from dire poverty for the first time in human history. We have the skills and resources to offer emerging nations a suite of solutions to eradicate hunger, thirst, and insect born diseases from the human experience. Unlike getting a man to the moon, we already have the technology and the expense is modest, but with returns of unimaginable benefits. The American people are known for their generosity, innovation and courage. Will you stand with me and build a new future? As we reinvent our economies to be sustainable, emerging nations can find their own authentic path to prosperity with our help. There is no conflict between our greatness and theirs; only the courage to ask – "How?"

Having described these factors; the next step is to determine if they are being used. An evaluation was conducted of eight websites in the Greater Boston area for use of these psychological factors. All evaluated organizations were involved in the residential energy conservation sector but had different functions including funding, community education or energy efficiency services for homeowners. The evaluated websites revealed a low incorporation of these psychological factors. Generally organizations scores in the private sector underperformed while nonprofit organizations who embraced social marketing outperformed. Only one organization utilized all three of the key psychological factors—knowledge about related solutions, positive attitude, and locus of control. All organizations utilized two factors—knowledge about the primary mission and knowledge about related solutions. While locus of control and positive attitude factors were used more intermittently.

The website evaluations determined the content tended towards a more clinical or scientific presentation and lacked any vision associated with the positive attitude factor. As demonstrated, a powerful vision using a positive attitude is important but none of the ten evaluated websites had a comparable declaration or moral imperative. This broader vision and imagery is consistent with the themes of Break Through, a book written by the authors of *Death of Environmentalism*. Such a vision could match Americans desire for affluence by meeting their post material needs including creativity, self actualization and a community of common purpose. Furthermore, the positive attitude factor has the potential to be incorporated into social marketing messages.

Funding

This paper also examines innovative financing partnerships or products that bypass traditional financial institutions. For nonprofit organizations the use of social marketing ties into their funding strategy since their services or goods are a combination of private and public benefit. An example is a hybrid financial organization combining social mission with a commercial funding strategy. These hybrid organizations include community banks, credit unions and venture philanthropy capitalists.

While removal of financing barriers alone is not sufficient to increase energy efficiency projects, it can improve the cost-benefit calculations. Another financial strategy for nonprofits is to offer services or products when asking for donations. This is possible in part because of the flexibility shown around classification of the benefits that nonprofit organizations can offer. These benefit classifications are a key consideration for nonprofits when deciding on their value propositions as part of a funding strategy. Sources of income should have a benefit that is consistent and valued by the providers of the income. In other words the nonprofit is making a sales pitch that the financial support is justified or being traded for a desirable service the nonprofit offers. For example, the LEED building placard provides USBGC with revenue and the building owner with marketing credibility. A second example is Public Broadcasting Stations (PBS) which offers memberships during the pledge drives that provide donors with discounts to other cultural organizations such as museums. The relevant working principles are:

1. Different sources of income are appropriate to support specific missions and services. For example, grants with outreach campaigns and annual foundation contributions with capital building projects.
2. The income portfolio should be tailored to reflect the various services to beneficiaries and their source type of income provided. Economic efficiency and maximizing the appeal to supporters is a requirement even for nonprofit organizations.

Community Banks provide an example of these working strategies. Community banks demonstrated financial innovation by providing loan products with more attractive terms than private counterparts – commercial banks. These banks were originated to assist their communities in addressing social needs but have expanded to address environmental concerns of the community including energy efficiency. Banks have "green" products with improved financial terms for projects aimed at improved efficiencies, for example insulation or renewable energy such as solar powered water tanks. The financial concessions include zero interest loans and energy efficient mortgages which enables homeowners to take out additional principal to fund energy efficiency projects. One specific case of a community bank leading is One PacificCoast Bank. The bank has integrated the Natural Step methodology into their management practices. One PacificCoast Bank has committed to becoming carbon neutral and offers products targeted for energy efficiency project funding.

A second type of hybrid organization is venture philanthropy capital (VP) firms which are willing to accept lower rates of return in exchange for meeting a social or environmental benefit. VPs - like their corporate private equivalents – provide funding for a specific period and expect to make a return on their capital. Like community banks, VPs also offer advantages not available to their corporate sector rivals. In terms of organizational innovation, this new form of philanthropy offers advantages for creating partnerships. Besides funding, venture philanthropists can provide additional services such as strong in-house management and close monitoring of grantees.

These services can build strong organizations and new networks when they provide funding, technology and expertise to organizations receiving funding or grantees. The network provides a means for these organizations to share lessons learned and co-operate with each other. As a result the VP is often in a better position to help and offer valuable advice to managements who are launching or growing their organizations. A long term study by Latham .et al (2000), found venture philanthropy costs exceeded grant sources but the cost increase was offset by improved success for the recipients [16]. Other general challenges of VPs included increased implementation costs; power gaps between grantors and grantees; and culture class between VP and nonprofits [16].

This study also focused on the Center for Venture Philanthropy (CVP) efforts based in the Bay Area, CA (USA). The CVP was held up as an exceptional example of what is possible. The CVP founding of the Environmental Solution Forum (ESF) program resulted in creating best practices for an entire field and explicitly connected grantees with other network members. These network connections lead to members being able to tap each other for resources and expertise. These reciprocal relationships create authentic partnerships and collaborative goals with benefits across the entire sector.

Results: A New Model

In general, effective business partnerships will be needed to entice homeowners into action. Current homeowners' inertia relates to the perception of energy efficiency as an involved process with technical aspects and time commitments in exchange for uncertain potential savings. Conservation is also unlikely to generate excitement while energy costs remain low (US market) and marketing messages are based on aversion. Communication strategies that tie the private benefit of energy savings to the public benefit of climate change have to go beyond education. The key is breaching the gap from education about climate change impacts to a focus on individual action that can help. Therefore, communication initiatives should include a dedicated staff to provide guidance and continued support to homeowners throughout the process of increasing the household's energy efficiency.

The greater Boston area already has a robust community of sustainable organizations able to communicate and meet these needs. This community is necessary to offer consumers an integrated and streamlined product for energy efficiency projects. Moreover, given the number of and the depth of technical expertise involved, it is unlikely that a single organization could effectively address all aspects of residential energy efficiency projects. Therefore the optimal model is a network of organizations across the sector to coordinate and provide seamless one stop shopping for homeowners.

A good illustration would be employees who own their homes within the Harvard University community. Harvard has well established sustainability practices on campus to cover both buildings and individual behavior change strategies .The initiatives for behavior change range from peer advocacy in dorms, to competitions among labs and offering subsidies to employees for using public transportation. Furthermore the university has developed innovative financing by setting up a revolving fund where loans are issued (based on acceptable rates of returns) to finance renewable energy, upgrades to existing facilities and community outreach on campus.

Harvard University is ideal as a host organization. One reason is the existing relationship between the university and the Harvard University Credit Union. This partnership could be leveraged to provide funding for energy efficiency projects as an employee benefits. For the employee who takes out loans, the repayments could be deducted from payroll and sent directly to the credit union. When human resources manage employees' payroll deductions, a potential benefit for the credit union is a reduction of administrative costs. In addition, if the employer was willing to provide capital from a revolving fund or guarantee loans, then the credit union would have access to cheaper capital. In exchange, for these services the credit union would pass on the savings with lowered interest rate loans to employees.

This partnership would provide multiple advantages. There is an economic incentive of improved affordability for homeowners and no additional payments to make (if part of payroll) while the community benefits from reduced carbon emissions. For the employer, advantages include employee recruitment and retention, and an additional opportunity to demonstrate its environmental commitment. More importantly, this represents a repeatable model for any credit union with a membership base tied to a specific employer and could be used across the United States. The possible leverage is significant if you add credit unions associated with government (federal and state) employees. The combined assets for federal charted and corporate credit unions in the United States were $1,002 billion [17] versus $12,068 billion for corporate banks [18]. Any initiative, like credit unions, that can be rolled out across regional and national levels would lead to significant energy use reductions.

Another set of advantages is related to increased participation rates because a number of common barriers are already addressed. For a start as a member of the Harvard community, employees are exposed to behavior change campaigns which usually involve a reward (team competition or a catered social event) and having seen the energy savings are more likely to "take their work home". The university also communicates ongoing efforts through events and publications including an event hosted by the President Faust with Al Gore speaking. The culmination is that employees have already experiencing multiple communications. The "three-time convincer" concept states that three times is the minimum number of communications for a consumer to buy into a product message [1].

The Harvard University example can be used to create a more generalized model for adoption of energy efficiency projects. The relevant question becomes "What services are required to meet all the homeowners' needs?" An assessment of these needs was derived from interviews and websites evaluations. The key components as follows:

(1) As long as the cost of energy is low relative to other expenses, a mixed (private & public) benefit model which gets homeowners to "yes". As a public benefit, this might be to incorporate volunteering or community spirit efforts. While a private benefit should be tying energy assessments to other services such as a discount on tuning up the furnace or home owners insurance. The municipalities when sending the annual property tax or rates should promote energy efficiency.

(2) Individual behavior integrated with methods to motivate homeowners towards action. Motivating individuals, requires the presence of three key components - a clear statement of the problem, a related action item and an outcome which provides a combined benefit for the individual and for their community. The individual's contribution as a percentage of all the total

reductions for their community and the community total. The aggregated numbers should be tied to a larger vision – e.g. CO_2 reduction equivalency in number of trees planted - can be communicated via a social networking website.

(3) One point of contact to integrate a network of vendors for the entire project from concept, to implementation to independent validation of installed energy efficiency improvements.

(4) The need to provide a short list of organizations that can be mixed and matched together to provide all the technical functions. These technical functions include funding, product experts, energy assessment, home improvement providers and validation, clear presentation of before and after reporting based on energy savings metrics.

(5) High level of customer service to assist with understanding the cost benefit analysis of various goods or services. Essentially create a plan sequenced and manageable steps so an owner can complete a list over several years. This would be a report incorporating visual aids aimed at providing homeowners with a more intuitive benefit presentation.

(6) Vendor knowledge to manage the patchwork of incentives, tax rebates and other government subsidies from state and local government and utilities. While energy efficiency is enjoying a flurry of legislative activity, it is impossible for homeowners to keep current and minimize their upfront costs. One current example, to correlate state incentives, is DSIRE (*Database of State Incentives for Renewable Energy*) maintained by US Department of Energy for renewable and energy efficiency

These components are consistent with other studies. "Driving Demand for Home Energy Improvements" states that market transformation should be the ultimate goal for energy improvement sector [1]. The criterion for market transformation is a shift in the structure such that businesses can operate without subsidies, e.g. additional public funding, because of a decrease in barriers (LBNL, 2010). The identified necessary components are: development of customer interest, workforce skills, private financing tools and contractor networks [1]. Comparing these with the six components above, the utilization of incentive such as DSIRE (#6) is a short term crutch. The others are consistent but at a more micro level. For example, components three thru five correspond to the contractor networks discussed in Driving Demand.

In addition to these components, homeowners continue to struggle with understanding the current energy efficiency of their homes. There are a number of websites to help home owners assess their home's current energy efficiency and point them to utility companies for assessments. These tools may be informative but few are designed to be aesthetically appealing or convey information which can be grasped quickly or tied to definitive actions. For the residential market there is a lack of effective tools for energy modeling software which can provide a simple metric. The software ideally would provide a single number - the energy used for a base unit of space (sq. ft / cubic meters) where weather conditions and single person consumption have been normalized. Therefore, the market place is lacking a method for clear communication of the cost-benefit analysis. The conclusion will discuss how these observations and recommendations can be applied to residential energy efficiency sector.

Conclusion

The recommendations for homeowners' needs have focused on the role of funding, behavioral change and business to business collaboration for residential energy efficiency. The conclusions surrounding current practices are the foundation for making recommendations to reach a new reality. These recommendations include specific tools as well as broader policy strategies and each can be implemented independently. Discussed below, the recommendations start with the broadest focus and as the reader progresses the focus continually narrows.

Policy Recommendations

- Partnerships developed that co-brand efficiency message with other environmental efforts.
- Incentives for non-owner occupied buildings.
- Database development as a foundation for understanding performance metrics for residential properties. As part of convincing homeowners, shift reliance from computer models to monitoring (before and after) and increase the level of transparency.

Integrated Benefits

- Utilize existing organizations to tie their products to conservation efforts such as savings on homeowner's policy or furnace service contract. Another option would be to get environmental groups to subsidize their members' energy efficiency projects as a benefit of membership akin to the PBS membership model previously mentioned.
- Utilizing volunteers to improve efficiency of public buildings which provides the volunteers with learning opportunities, saves money and demonstrates improved comfort to visitors.
- Track and publish efficiency projects by neighborhood for competitions to generate friendly community rivalry.

Visual Assessment Report Recommendations

- Create a universal certification among energy assessment providers. Similar to the UL® (Underwriters Laboratories) Safety Standards.

- Reduce the reports to a more visual experience. Currently energy assessments are data laden, requiring additional time for homeowners to interpret information and formulate a process for implementation. In one study, one half of the subjects received a numbers based report and the other half the feedback included a smiley or sad face. The first group households' usage trended towards the mean - even those where originally usage was less. In contrast, the second group's lower users saw a smiley faces maintained their usage level and didn't inflate to the mean [1]. One suggestion is a template for energy efficiency could be based on familiar restaurant guides like Zagat. Restaurant guides capture multiple performance metrics with symbols to convey price, food, décor, and service. For energy efficiency these metrics could include cost effectiveness, comfort, health, and effort. As an example, why not equate heated air leaking outside as the equivalent to leaving a door or window open x inches (centimeters) in winter?

These recommendations by themselves are unlikely to generate excitement without a strong social message. The final and most important concluding thought is about solutions utilizing psychological factors more effectively. The book *Break Through* (2007) has a subtitle of "*Why We Can't Leave Saving the Planet to Environmentalists".* The answer to the question is because environmentalists are approaching climate mitigation strategies as a technical and informational problem. These are necessary elements of the solution but are not effective as a call to action or basis of inspiration. The vision statements and passion demonstrated in the psychology section is what is missing. The most pivotal moments in the last century for the United States were the military engagement in World War II, the Civil Rights Movement and the Man on the Moon Campaign. The speeches (President Roosevelt, Martin Luther King and President Kennedy respectively) associated with these new initiatives did not sound like Al Gore's "Inconvenient Truth" film in language or imagery.

As obvious and technically feasible the solutions of energy efficiency are, unless we can match the spirit of past historical moments, the inertia is likely to continue. Strong social messages are about presenting our future aspirations as a community and society. For example, the American Revolution quotes were intended to capture the imagination and motivate individuals. The American Revolution successfully mobilized colonists with the declaration "No taxation without representation" and not "You can save 10% on your taxes". Furthermore, the colonists understood the importance of community demonstrated by Benjamin Franklin's quote "We must ***all*** hang together, or assuredly we shall all ***hang separately****".*

References

[1] Lawrence Berkeley National Laboratory (LBNL), Environmental Energy Technologies Division. *Driving Demand for Home Energy Improvements: Motivating residential customers to invest in comprehensive upgrades that eliminate energy waste, avoid high bills, and spur the economy*. September 2010, LBNL-3960E.

[2] Niemeyer, Shirley. *Consumer voices: adoption of residential energy-efficient practices.* International Journal of Consumer Studies 34 (2010) 140–145.

[3] Attaria,S. et al., (2010). "Public Perceptions of Energy Consumption and Savings". Proceedings of the National Academy of Sciences, September 14, 2010:vol. 107, no. 37, 16054-16059.

[4] Allcott, Hunt,and Sendhil Mullainathan. *Behavior and Energy Policy.* Science 327.5970 (2010): 1204-1205. Academic Search Premier. EBSCO. Web. 19 Sept. 2010.

[5] Giudice, Paul (Commissioner, Massachusetts Department of Energy Resources). “Renewable Energy's Future in New England”. Speech at the Restructuring Roundtable. Boston, MA. Sept. 17, 2010.

[6] Pacalal, S. and Socolow, R. *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies.* Science 13 August 2004: 968-972.

[7] National Academy of Sciences (NAS); National Academy of Engineering; National Research Council. America's Energy Future: Technology and Transformation: Summary Edition Committee on America's Energy Future. Washington, DC: 2009.

[8] The Mexican Water Treaty: Treaty Series 994 (59 Stat. 1219) *US-Mexico Treaty for Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande*. 1994 via website from http://crc.nv.gov/1944mexicanwatertreaty.htm Accessed: 15/01/2011.

[9] Kotchen, J. *Offsetting Green Guilt*. Stanford Social Innovation Review, Spring 2009: 26-31.

[10] Hardin, G. *The Tragedy of the Commons.* Science 162:1243-1248 (1968). American Association for the Advancement of Science retrieved from: http://www.jstor.org/stable/1724745 Accessed: 18/10/2008 13:05

[11] Young, D. *Financing Nonprofits: Putting Theory into Practice.* National Center for Nonprofit Enterprise, 2007.

[12] Nordhaus, T. and Schellenberger,M. *Break Through: Why We Can’t Leave Saving the Planet to Environmentalists.* New York: Houghton Mifflin Harcourt, 2007.

[13] Johnston, G. “Influencing the Individual to Effect Behavior at a Broader Societal Level”. Capstone Project: Harvard University, ALM in Sustainable & Environmental Management, 2009.

[14] Kotchen, J. *Offsetting Green Guilt.* Stanford Social Innovation Review, Spring 2009: 26-31

[15] Hines, Jody M., Hungerford, Harold R. and Tomera, Audrey N. *Analysis and Synthesis of Research on Responsible Environmental Behavior: A Meta-Analysis*. The Journal of Environmental Education, 1987,18: 2, 1-8 via website article was downloaded by: [Harvard University Graduate School of Education] On: 20 January 2011.

[16] LaFrance, S. and Latham, N. *Taking Stock of Venture Philanthropy*. Stanford Social Innovation Review, Summer 2008; 6, 3.

[17] National Association of Federal Credit Unions (NAFCU). NAFCU 2010 Report On Credit Unions, December 1, 2010 via website from: http://www.nafcu.org/Tertiary.aspx?id=1916, Accessed: 06/05/2011 11:30.

[18] Federal Deposit and Insurance Corporation, *Statistics at a Glance as of December 31 ,2010*, via website from: http://www.fdic.gov/bank/statistical/stats/2010dec/industry.html, Accessed: 06/05/2011 12:00.

The Tri-Fecta: Comprehensive Review and Best Practices in Impact, Attribution, and Retention of Behavioral Programs and Beyond

Dr. Lisa A. Skumatz, Skumatz Economic Research Associates, Superior, CO USA

Abstract

The California Public Utilities Commission (CPUC) and California Institute for Energy and the Environment (CIEE) recognized that evaluation/attribution methods have reached a point that they must evolve in order to provide credible evaluation results for the next generation of programs. Two primary factors have complicated the methodologies that have been applied to energy efficiency programs:

- Transition to more behavioral, outreach and other non-measure-based programs (education, advertising), making it especially hard to "count" impacts, and
- Increased chatter in the marketplace, in which consumers may be influenced by any number of utility programs by the host / territorial utility (the "portfolio") as well as influences from outside the territorial utility (national, neighboring programs, movies / media, etc.).

The project conducted a comprehensive review of current state of the art, and identified best practices and gaps in methods for attribution and evaluation of traditional and behavioral programs. The project used interviews, literature review, and analysis to examine technical, research, and policy issues associated with the key elements of attribution of savings to programs: 1) impact evaluation, or gross savings estimates; 2) net-to-gross (NTG) ratios and its components, free ridership, spillover, and 3) retention of savings.

Beyond reviewing the "state of the art" in traditional attribution work, we also examined research and policies related to attribution for behavior, education, and training-based programs, and issues related to disentangling the effects from multiple programs and deliverers (marketplace "chatter"). Near- and long-term implications and recommendations for program design, evaluation, outreach, and benefit-cost for programs across the US are also presented.

Project Introduction/Context

This project, funded by the California Public Utilities Commission (CPUC), focused on examining current practices, state-of-the-art, gaps, and associated policy issues related to evaluation of behavioral energy efficiency programs[1]. The project was part comprehensive literature review of the status quo in this fairly technical field, and part analysis of gaps, promising approaches, and next steps, and focused on four key areas: gross savings; attribution / free ridership / net to gross (NTG); non-energy benefits (NEBs); and persistence. These elements all play a role in identifying how much savings can be attributed to a program. Gross savings count the kilowatt-hours (kWh) associated with the initial widgets or behaviors changed; NTG adjusts by what would have happened without the program to estimate "net" attributable kWh savings; NEBs provide estimates of the indirect effects of programs (greenhouse gases, utility savings, participant impacts); and measure lifetimes (also called estimated useful lifetimes or EULs) determine how long the estimated annual savings persist, and should be "summed up". Balanced against program costs, various sets of these impacts are rolled up to identify the benefit/cost analysis associated with programs. This paper focuses on the savings, NTG, and persistence topics.

[1] This paper presents the findings from one of eight white papers on behavior and energy that were funded by the CPUC and managed by the California Institute for Energy and Environment (CIEE). This work does not necessarily represent the views of the CPUC or CIEE or any of its employees. The white papers are available at: http://uc-ciee.org/energyeff/energyeff.html.

Evaluation results have an array of applications, including program design / refinement, selection of measures, targeting, as well as making program and reward decisions that put significant investment dollars at risk. This project worked to assess the analytical and experimental design methods being applied and identified weaknesses, gaps, and promising approaches. As programs have evolved, evaluation methods must be reconsidered in order to provide credible results for the next generation of programs. Two primary factors have complicated the methodologies that have been applied to energy efficiency programs:

- **Behavioral programs**: Transition from "widget"-based programs to more behavioral, outreach and other non-measure-based programs (education, advertising), making it especially hard to "count" impacts, and
- **Multiple influences**: Increased chatter in the marketplace, in which consumers may be influenced by any number of utility programs by the host / territorial utility (the "portfolio") as well as influences from outside the territorial utility (national, neighboring programs, movies / media).

As a result, attributing or assigning responsibility for changed behaviors and the adoption of energy efficiency measures or services is muddied and challenging. Although the paper initially focused on behavioral programs, the shortage of evaluation work in behavioral programs led to an expansion from a narrow to a wider definition, incorporating education / outreach, behavioral, measure adoption decisions, and participation decisions. We[2] reviewed more than 250 reports / articles, review of state / regulatory policies nationwide, and reached out to 100 professionals / experts in the field for interviews. The full study is available on-line at CIEE or SERA / www.serainc.com websites.

Section 1: Impact / Gross (Adjusted) Savings Estimates

The first step in the attribution of program effects from an energy efficiency intervention is developing an estimate of gross energy savings. There are generally five classes of methods currently used for estimating gross impacts, described below.

Table 1: Strength and Weaknesses of Impact Evaluation Approaches

Method	Description	Strengths	Weaknesses
Measurement & Verification (M&V)	Metering or estimating key parameters from a sample of participants and applying it to all participants.	Statistical properties and real-world measurement;	Expensive to acquire large sample; needs survey data to pull out operational changes; behavioral measures may not always be meter-able
Deemed Savings	Applying "deemed" or agreed-upon savings obtained from other evaluations or manufacturers' data to all program participants.	Simple, inexpensive May be suitable programs or measures with consistent performance or that aren't weather-dependent	Inappropriate for new measures, measures with changes, programs with multiple measures /combinations that may have interactive effects, weather-dependent programs; little existing data in behavioral programs
Statistical Analyses	Involves applying statistical regression models to utility billing or metering data of all program participants.	Statistical properties and real-world measurement Can be mis-specified; different researchers often derive different	Expensive to acquire large sample; needs survey data to pull out operational changes and behavioral elements.

[2] The context for this paper (California) relates to, but is not exclusive to, the situation of programs run by utilities with oversight by a public service commission and where shareholder incentives are at stake and depend on the determination of attribution. This review has relevance beyond this situation, but readers in other states may need to make a few adjustments in terminology, etc. Skumatz Economic Research Associates (SERA) was commissioned by CIEE to conduct this review. The lead author wishes to thank the following for assistance in preparing the white paper: D. Juri Freeman, Dana D'Souza, and Dawn Bement (Skumatz Economic Research Associates), Carol Mulholland, Jamie Drakos, and Natalie Auer (Cadmus Group), and Gregg Eisenberg (Iron Mountain Consulting).

		estimates Perhaps more flexible for measuring behavioral programs (more explanatory variables, etc.)	
Market Progress / Market Share	Uses information from sales, shipments, or other similar data to develop estimates of changes in sales (and implied usage) of program-recognized energy-efficient equipment relative to non-program equipment. Estimates of the associated energy (and/or demand) savings are then calculated.[3]	Shipments data available from several vendors; fairly straightforward Some indirect regression methods can provide information on exit timing, needed rebates, and other findings	Data weaknesses from the usual sources including differences in shipment vs. sales, regional / territorial data collection difficulties. Different data can give different answers Doesn't address behavioral programs except purchase decision.
Surveys	Often needed to estimate the savings-related changes from behavioral / educational / social marketing programs, perhaps in concert with the market progress methods described above.	Well suited to behavioral programs Often needed to support other methods Experimental design with random assignment to test and control groups of adequate size can provide estimates.	Common concerns around self-report, bias, etc. There can be difficulties linking back to direct savings (and some simply don't try to count or evaluate these programs), Can be expensive for large samples

The methods, strengths, and weaknesses of each method are fairly well known; most of the methods are fairly well-established, and used regularly, although a longer discussion is included covering the issue of sales / tracking methods and some pilot analyses aimed at addressing some of the weaknesses of these approaches[4].

Ultimately, we conclude that there have been very few well-designed, large sample evaluations of behavioral-type programs, and that these programs require strong experimental design to provide reliable estimates. We note that market assessments "up-front", and market and appliance /equipment saturation surveys are critical inputs to provide adjusted gross estimates and to design programs that are needed in the marketplace.

These approaches have generally served to provide gross estimates of programs, even if there are a few issues arising because of the switch toward market and behavioral programs. Interviews with leaders in the field and review of the literature indicated a number of issues associated with the application of these methods to the evolving generation of programs:

- **Problems and best practices suggestions for (program design and) impact evaluations**: Our study indicates that an up-front understanding of *program goals* against which progress is being measured is not always available, thereby complicating evaluation. In addition, the field should consider more regularly conducting *market assessments* – up front – so it becomes clearer what actions are needed in the market and when a program should exit the market – and to allow better understanding of the market, identify needs, and provide a baseline for program evaluations. As part of that baseline work, market and appliance / equipment *saturation surveys* need to be re-introduced to allow better understanding of the market, identify needs, and provide a baseline for program evaluations.
- **Gaps and methodological improvements for impact studies***:* The study indicates that *logger studies* are needed for some types of measures (e.g., lighting) to improve the reliability of impact

[3] One innovative approach indirectly measures market share by estimating the effect on a decomposed price differential and tracking the size of the coefficient for the efficiency features of the measure(s). See Skumatz 2007 and Skumatz 2009.
[4] See the two AESP white papers on the AESP member's web site, one by Dimetrosky, et.al. and one by Skumatz.

studies. There has been a gap in detailed assessment of behavioral programs, and the modeling approaches used for assessing behavioral programs could be improved.

- **Baseline and overlap issues**: There is a significant problem in using *program records* for establishing a baseline: this type of information is collected to support rebates and not evaluation, so that useful baseline data are not collected up-front. To date, no studies have identified revelatory methods of isolating impacts for individual programs from "noisy" markets (markets with multiple programs influencing behavior). Estimating the impacts from one program is difficult – many suggest it may only be possible to estimates market effects from entire portfolios of programs.
- **Adaptations for educational / behavioral programs**: Education and behavioral program evaluations have been evaluated, but tend to require *tailored*, rather than prescribed, *evaluation methods*. Impacts may be indirect in some cases, but direct and indirect impacts can be measured for many programs with up-front experimental design methods and sufficient sample sizes. Work in developing creative adaptations to better fit behavioral programs would be valuable.

Section 2: Net to Gross

The literature provides many examples of uses to which free ridership, spillover, or NTG ratios are relevant.[5] Free ridership helps to identify superior program designs and helps to identify program exit timing. Spillover helps to assess the performance of education / outreach /behavioral programs,[6] and it helps to identify program exit timing. Not examining free ridership and spillover *ex post* will make it impossible to distinguish and control for poorly designed / implemented programs, as well as for programs that may have declining performance over time and may have outlived their usefulness, at least in their current incarnation. Some interviewees said 'deemed savings are ridiculous' for this reason.

Net effects are a significant element in assessing benefits and costs for a program, and the associated results can, in some states, determine the start, continuation, or termination of a program's funding. To estimate program effects above and beyond what would have happened without the program involves identifying the share of energy-efficient measures installed / purchased that would have been installed / purchased without the program's efforts. Some purchasers would have purchased the measure without the program's incentive or intervention. They are called "free riders" – they received the incentive but didn't need it. Others may hear about the benefits of the energy-efficient equipment and may install it even though they do not directly receive the program's incentives for those installations and are not recorded directly in the program's "count" of installations. This is called "spillover," and there are three types of spillover:[7]

- Inside project spillover occurs, for example, when refrigerators are rebated, and the person receives / installs that equipment, and then later installs an energy-efficient dishwasher.
- Outside project spillover occurs, for example, when a builder receives rebates on one project, but installs similar efficient measures in other homes without rebates.
- Non-participant spillover occurs, for example, when a builder hears about energy efficiency and does not participate or receive any rebates, but decides to install efficient equipment to serve his customers or to keep up with other builders, etc. No incentives were provided for these measures.

---

[5] This paper does not discuss "takeback". An example of takeback is when a homeowner turns up the thermostat after more efficient HVAC systems are installed. This review found little recent work on this topic.

[6] For some of these types of programs, spillover is actually the point of the program, and omitting it ignores important program effects. Ignoring free ridership (in favor of "deemed" NTG figures) allows the continuation of poorly-designed or implemented programs, which wastes ratepayer money.

[7] The first two examples are often referred to as Participant Spillover and the third example as Non-Participant Spillover.

The combination of the “negative” of free ridership and the “positive” of spillover are computed as a “net to gross” (NTG) ratio, and are applied to the “gross” savings to provide an estimate of attributable “net” savings for the program.[8] The NTG ratio only equals free ridership (FR) if spillover (SO) is (or is assumed to be) zero. The NTG, or its components, have been addressed in four main ways, described below. Our review and interviews identified key strengths and weaknesses of each method.

Table 2: Strength and Weaknesses of NTG Evaluation Approaches

NTG Method	Description	Strengths	Weaknesses
Deemed (stipulated) NTG	A NTG ratio is assumed (1, 0.8, 0.7, etc.)[9] that is applied to all programs or all programs of specific types. This is generally negotiated between utilities and regulators or assigned by regulators	Simple, uniform, and eliminates debate; no risk in program design or performance; inexpensive.	Does not recognize actual differences in performance from different programs, designs, or implementations.
NTG adjusted by models with dynamic baseline	A baseline of growth of adoption of efficient measures is developed, and the gross savings are adjusted by the changes in the baseline for the period	Can reflect differences in performance for good or poor designs and implementation.	Complicated to identify appropriate baseline; data intensive; potentially expensive; introduces more risk to program designers related to program performance; may lead to protracted discussions.
Paired comparisons NTG	Saturations (or changes in saturations) of equipment can be compared for the program (or “test”) group versus a control group. The control group is similar to the test group but does not receive the program. Ideally, pre- and post- measurement is conducted in both test and control groups to allow strong “net” comparisons.	Can reflect differences in performance for good or poor designs and implementation; straightforward concept and reliable evaluation design	Control groups can be difficult to obtain; if imperfect control groups are used, statistical corrections may be subject to protracted discussions.
Survey-based NTG	A sophisticated battery of questions is asked about whether the participant would have purchased the measures or adopted the behavior without the influence of the program. Those participating despite the program are the free ridership percentage. These are then netted out of the gross savings. Spillover batteries can also be administered to samples of potential spillover groups (participants, non-participants).	Provides an estimate of free ridership and spillover; can explore causes and rationales.	Responses are self-reported leading to potential bias or recall issues; may be expensive; can be difficult to get good sample of respondents for free ridership; requires well-designed survey instrument which can be long and which affects response rate.

Complexities / Controversies in Measuring and Using NTG

Measuring spillover is more complex than measuring free ridership. Free ridership emanates from the pool of identified program participants; the effects from spillover are not realized from the participating projects and, in many cases, not even the entities that participated. Identifying who to contact to explore the issue of spillover and associated indirect effects can be daunting. Perhaps as a consequence, we found that a number of states consider free ridership in the calculation of NTG, but do not include spillover in their analyses of program effects or in regulatory settings (including California). Reasons include:

- Concerns about rigor: Some suggest that evaluations carefully estimate (gross) savings that were delivered, but then the savings (and, directly, the associated financial incentives to the agency delivering the program) are discounted by a free ridership factor measured by methods that are less “trusted” – in other words, specifically measuring gross savings based on statistical analysis of meter

[8] The literature shows computations of this NTG ratio by adding the factors (1-FR+SO) or by multiplying the factors ((1-FR)*(1+SO)). Both are used in practice.

[9] If the NTG is less than zero, then this reflects the likelihood of some free ridership.

readings/ billing records, compared to measuring free ridership and/or spillover based on self-report surveys of hypothetical decisions and behavior.

- Confidence Intervals: Another controversy relates to the fact that only a small minority of free ridership, spillover, or NTG studies report any confidence ranges, or even discussions of uncertainty.
- Indirect Programs: Furthermore, most behavioral and educational programs seem to be treated as indirect programs and not included in regulatory tests. This has a problematic side effect: lack of credits for benefits or savings from these programs results in an under-investment in these efforts. Because of their spillover implications, this puts educational (and potentially behavioral) programs at a disadvantage in portfolio development, designing rewards and incentives, and in resource supply applications.
- The potential for error and uncertainty associated with these measurements, because of difficulties in (1) identifying an accurate baseline; (2) identifying and implementing a control group; or (3) relying on self responses to a survey.
- The expense of high quality analysis – with arguments that the money could be better spent on program design, implementation, incentives, etc.
- Baselines and effects are harder and harder to identify and analyze as programs move up stream, involve different levels of vendors and other actors, and lead to changes in baselines up the chain. In addition, program spillover complicates the identification of a reasonable control or comparison group. Some studies have made it clear that using sensible assumptions (code as a baseline) is not a reliable approach; Mahone (2008) notes that for at least the multifamily sector, none of the buildings were being built to the level of baseline codes – i.e., they were underperforming, so that the actual baseline of standard practice was below the baseline of codes.[10]
- The difficulty in separating out the effects and influences of different programs within a marketplace (own utility / agency and outside utility / agency), often called "chatter".
- Documenting what "would have happened" is the biggest challenge in evaluation (Saxonis 2007). Many interviewees suggested that strong market assessment is needed up-front to provide the maximum amount of baseline information. However, when it comes to the dynamic retail sector, it may be impossible to predict what they would have done without the program (Messenger 2009) – especially if changes occur upstream.[11] More research on standard practice in the field would provide a stronger basis for baselines and provide a sounder basis for determining NTG ratios.
- Concerns that using measured NTG or free ridership ratios introduces a great deal (to some, an unacceptable level) of risk or uncertainty into the potential financial performance metrics for the program, which will lead to "same old / same old" programs and reduce innovation in program offerings.[12]

In some states (e.g., California), these measurements have huge potential financial impacts in which utilities may receive financial awards for running programs and running them well. As noted above, NTG ratios can be used to reduce (incorporating free ridership) or potentially expand (if spillover associated with the program exceeds free ridership) the amount of savings attributable to a program. Including only free ridership represents an analytic asymmetry that undervalues energy efficiency by incorporating only subtractions (such as free riders) from gross savings and ignoring potential additions (such as spillover). Until these issues are addressed, given the financial implications, it is unlikely much additional progress will be made in a more comprehensive treatment of free riders, spillover, or NTG in the regulatory realm.

[10] In this case, NTG would be estimated as greater than "one," since the energy efficiency program improved performance over the standard practice baseline.

[11] For example, some upstream changes may spill over to areas that might otherwise be considered potential control areas. If a manufacturer is induced to change the manufacture or mix of product, and they do so for California which is a big enough market to swing production in general, then the new product lines will become available in the potential control areas and the (important) market effect is then reduced.

[12] Innovation is valuable, but agencies will not innovate (cannot justify innovating) in programs unless the risk is reasonably predictable. However, on the other side, regulators must assure that the reward structure doesn't encourage ineffective programs and that funding is spent appropriately and prudently.

One key question is the degree of accuracy needed for the various applications. Certainly, NTG doesn't have to be highly precise for program design, feedback, marketing and optimization; but greater accuracy needs arise when high dollars are involved, like some of the shareholder returns computations from regulatory tests. However, we posit a central "chicken and egg" question: if NTG isn't used for serious applications (like financial and regulatory computations), will the methods and studies receive enough attention to see them improved (and improved enough to meet the needs of the "serious" applications)?

Ignoring spillover (because we are concerned that the accuracy of the estimates is of concern) for a program for which spillover is a key goal and outcome increases the chances of making a "wrong decision" about that program investment – and eliminates the chance to improve that performance (assuming measurement breeds improvement). Estimating spillover and applying ranges or confidence intervals to the values in assessing the program[13] may be preferable to ignoring spillover. On the other hand, ignoring spillover for a low value program or for a program for which spillover is not an integral part may not be a significant concern. As one person put it, "not measuring <NTG> is not the answer."

State Practices and NTG Patterns

Several states use the California Standard Practice Manual, or large portions of it, for estimating energy savings, free ridership, non-energy benefits, and benefit-cost regulatory tests, including Oregon, Washington, Idaho, Montana, Wyoming, Utah[14], Iowa, Kansas, Missouri, New Mexico, and Colorado (Hedman, 2009). Several studies specifically examined state and utility practices regarding free ridership and net-to-gross and found that utilities treat the issue of NTG differently. In some, there is no regulatory agreement on NTG; in others, they measure only Free ridership. Other states say NTG is too costly and biased, or is not a priority, other select deemed values, and still others try to address NTG factors up-front in program design.

We also reviewed results from more than 80 evaluation studies from California, New England, and the Midwest that included NTG. The results are found in the following table.

Table 3: NTG Results Review

	Net To Gross , Free Ridership, Spillover
General results	• Most utilities and regulators exclude NTG or assume values that incorporate only free riders and range from about 0.7 to 1.0 (*ex ante*). *Ex post* results have been measured for many programs; spillover is measured much less often than free ridership (and spillover is more commonly reported in the Northeast than in California). • Most studies rely on self-report surveys using variations in questions incorporating partial free ridership/likelihoods; only a small percent used logit/ranking/discrete choice modeling. • Some studies included both *ex ante* and *ex post* NTG figures for the same program. The *ex post* values were generally 10-20% lower than the *ex ante* values. The most obvious exceptions were some cooking measure programs (*ex post* was about half the *ex ante* value), and some refrigerator programs that reported spillover values greater than 0.5. • Gaps included: Fewer than 10% reported confidence intervals; only a small subset covered NTG for gas savings; and very few studies identified free ridership for electricity savings; most considered only kWh effects.
Variations by measure type, program type or region	• Clear patterns for free ridership, spillover, or NTG results by measures, program types, and regions have not been demonstrated to date. The assumption is that variations in specific program design and measure eligibility definitions are important to results. NTG results in the literature are also affected by whether or not spillover is included in the assessment. • *Ex-post* free ridership clustered around 0.1-0.3 but ranged as high as 0.5 to 0.7 for some commercial HVAC / motors and refrigerator initiatives. *Ex-post* NTG clustered around 0.7-1.0, but dipped as low as 0.3 and as high as 1.3. The lowest free ridership was low income programs (as low as 0.03).

[13] Or looking for that threshold value of spillover that "turns the decision" may be another way to address the accuracy issue. If the threshold is outside the estimated range for spillover or outside any credible or feasible range based on the rough estimate, the program decisionmaking is improved.
[14] Utah only allows one year of lost revenues in the Rate Impact Test.

	Net To Gross , Free Ridership, Spillover
	• NTG for whole homes and home retrofits tended to be high (0.85 to 0.95), but ranged from 0.5 to more than 1.0. • Net realization rates were provided for about one-third of the programs, and the values averaged about 0.7 to 1.0. A number of values exceeded 1.0, including commercial HVAC rebate programs (1.07) and refrigerator rebate programs (1.15). Several programs showed net realization rates between 0.3 and 0.5 including several CFL programs, some refrigerator programs, some gas cooktop rebate programs, and some energy management system initiatives.
Variations for behavioral vs. measure-based programs	• Studies addressing NTG, free ridership, or spillover estimates associated with strictly behavioral programs were not found, and if available, are probably too few in number to lead to overarching conclusions or patterns.

Our findings and recommendations regarding NTG determination follow.

- ***Update methods to estimate NTG***. Historically, fairly simplistic measurement methods have been used to estimate free ridership. The computations have been based on self-reports. Sources of error with this method stem from faulty recall, bias toward claiming the program was not influential or influential, and from bias introduced in the form of hypothetical questions. Improved methods have been introduced that allow for "partial" free ridership (important in an era of multiple influencers and market chatter), and questions on "influencing factors" or "corroborating questions"[15] to develop more robust NTG estimates. Other studies have established multiple criteria for free ridership[16] or conduct long-term market tracking to tease out how much of gross savings to claim for the program.
- ***Recognize "credit-splitting or credit-sharing".*** One key refinement may be the recognition that we may not be able to attribute "causality" to one program or intervention, but may need to consider splitting the credit to account for chatter and multiple influences affecting measure and programs. One researcher notes "it may take a village to raise a behavioral kilowatt-hour sometimes" (Bensch 2009), and sharing the credit may be the right answer, as people may only pay attention if it is a 'whole choir singing the "save energy" song' (Bensch 2009). Sulyma (2009) argues that it is more than time to move beyond only "one" plausible explanation for impacts, and that probabilistic methods should be used to address this attribution issue.
- ***Incorporate Appropriate Experimental Design***. The experimental design approach has been well known for decades, with random assignment of eligible participants assigned to treatment and non-treatment groups, analyzed using discrete choice models to predict behavior. This helps address the baseline issue in a credible way. However, to implement this option would require the regulators, utilities, or agencies to "bite the bullet" in terms of the political fallout from those that want to participate but are put into the "no treatment" (or on hold for later treatment) bucket. This approach may be especially important for outreach and behavioral programs.
- ***Collect Data Promptly*****.** Improve data collection by introducing NTG-question batteries as part of the program participation documents ("real time data collection) to gather data near the point of decision-making and assure greater response rates (Gordon and Skumatz 2007). This may be suited to education and behavioral programs as well as "widget" programs, but needs testing, as the approach has not been widely applied.[17]
- ***Consider discrete choice modeling approaches*****.** These approaches introduce explanatory variables that help to address issues of imperfect control groups, unobserved factors, etc. to allow improved estimates of attributable impacts.

[15] For example, the questions might ask about the importance of the rebate in decision-making, whether the purchase was moved forward two years or more, whether they were already aware of the measures, and similar questions, and used these responses to validate or adjust responses to direct free ridership responses (Skumatz, Violette, and Woods 2004).
[16] In one study, free riders had to meet four criteria: aware of the measure before the program, intending to purchase before the program, aware of where to purchase the measure, and willing to pay full price. If the four conditions were met, the household or business was classified as a free rider.
[17] It has been suggested that the smart grid or technologies might enhance the opportunity for real time collection of some important data elements.

- ***Compromise on NTG for fiscal-related applications.*** A case might be made that the most "accurate" metric is pure *ex-post* measurement especially when those estimates are used for planning and reward purposes. To encourage program innovation, but balance risk to the program designers, consider a hybrid approach, with short term deemed NTG values for the near term (1-2 years), followed by NTG estimation work after that period. Another "tweak" to test to encourage innovation might be allowing differential rewards: upside incentives could potentially be larger than downside penalties for innovative programs. For some large, important, or innovative programs, negotiations for a priori values might be used.[18] Fiscal incentives must encourage (or at least not penalize) innovation, or only mediocre or "same old" programs will be offered – and they will be offered well past when they should be out of the market.
- ***Conduct comprehensive market assessment work for baseline support***, on non-participant spillover, and modeling of decision-making. This is particularly important for many training, education, and behavioral programs.
- ***Use Discrete choice and other modeling methods*** and statistical techniques to help address issues of imperfect control groups, unobserved factors, etc., to allow for improved estimates of attributable impacts.
- ***Compare results***: Accumulate results on elements of NTG in a database and continuously update with new research and evaluations, so comparisons and tracking are facilitated.

Section 3: Measure Lifetimes/Persistence/Estimated Useful Lifetimes (EULs)

The review of the work in persistence finds it a less controversial issue than NTG. The statistical and data collection methods and established best practices have largely been reflected in protocols.[19] The overall approach taken by most measure retention studies in the energy efficiency (EE) field is to estimate the median EUL of the measure in question. The EUL is usually defined as the median number of years[20] that a measure is likely to remain in-place and operable.[21] This amount of time is often calculated by estimating the amount of time until half of the units are no longer in-place and operable. The key data needed to derive these estimates are straightforward: installation location, measure(s) installed, date installed, and the date that the measure became inoperable or was removed. From these data, a basic measure life study can be conducted.[22]

While this task may seem straightforward at first glance, there are often considerable complications involved with obtaining EUL estimates. Measures often last for a long time, making it impractical to simply wait until half of the units fail in order to determine the median survival time. Measure lives are also frequently interrupted prematurely by the owners or employees of the residence or business in which the measure was installed. Obtaining unbiased EUL estimates, therefore, can require statistical analysis to (1) control for exogenous factors that might affect measure lifetime and (2) predict measure lifetimes based on empirical data. Furthermore, applications for this work require information on the projected results fairly early into the lifetime of much of the equipment installed as part of various programs, when a set of measures is young and only a relatively small portion of the installations may have failed. For example, protocols that were in place for many years in California required periodic verification of EULs when measures had been installed for fewer than five years. While important, this poses a particular

---

[18] This may cover programs such as those offered to only a very few large businesses (industrial, etc.), for example. This is suggested by the method NYSERDA is implementing for measuring NTG from their custom program that has very few participants (Cook 2008).

[19] Although the literature tends to test only one model or distribution (a potential weakness considering the variations in underlying technology and mechanics), and rarely presents comparisons or discussion of *ex ante* and *ex post* values or present comparisons to other studies of the same measures. The methods and EULs have evolved from the initial kernals in work for Bonneville Power Administration, presented in Skumatz and Hickman, ACEEE 1992.

[20] Or other time interval, as appropriate.

[21] "In-place and operable" is at least the most common definition of measure survival. Depending on the specific measure under inquiry, alternative formulations of the definition may be more appropriate.

[22] Enhanced data can improve the estimates; these issues are discussed later in the paper.

challenge, as EUL estimates are based on failures, and few measures projected to last 20 years or more would be expected to fail under that schedule. Finally, changes may be needed to the traditional time intervals to address newer behavioral programs, for which it is currently quite unclear what lifetimes may apply. Developing unbiased estimates of EULs under circumstances of limited data early in measure lifetimes is particularly challenging.

We conducted an extensive literature review of measure lifetime studies, and summarize patterns in values by measure type / end use and region of the country in Table 4.

Table 4: Strength and Weaknesses of Impact Evaluation Approaches

	EULs
General results	After early work in the Northwest, results broadly have gravitated toward values fairly similar to those in California's protocols, with some variations elsewhere. The State of California required *ex post* statistical verification, leading to minor refinements. There are a number of measures for which there are missing or inadequate data; the most glaring example is the nearly complete omission of retention information or estimates for behavioral programs.
Variations by Program type	Almost all EUL results are by measure, not by program design or incentive provided. Therefore, although measures have EULs, there are no variations for measures installed from programs designed as rebate vs. codes / standards, etc. Any program delivering a measure receives basically the same retention value for that measure.
Variations for behavioral vs. measure-based programs	There is almost no information for retention of behavioral programs including education / training, commissioning training, and similar programs. Widget-based programs have fairly thorough EUL information, with omissions for some measures (cooking, some shell, and others listed in the tables).

The research found the following:

- **Problems and best practice suggestions for effective useful life (EUL) studies:** Our study addressed some of the key issues that have hampered EUL studies in the past. Of particular note are the following: the need to assure that implementation databases are better structured to support evaluation research; use of appropriate sampling approaches when bundled programs are implemented; use of phone data collection only when measures are unique or memorable; use of panel surveys if possible; more enhanced modeling that supports the incorporation of tests of multiple model specifications; and, most importantly, benchmarking of the results against the findings for earlier years of the program and for similar programs around the nation.
- **Results and gaps in EULs**: A review of results from measure-based EUL studies around North America showed that measure lifetimes exist and are fairly consistent for many measure-based programs in commercial, residential, and industrial sectors. Relatively similar EUL values are being assigned by utilities across the country – perhaps with not enough recognition of the variation in operational hours by climate zone. The review also shows a lack of depth in studies in process equipment; some shell measures; and specific end-uses like cooking, refrigeration, and air compressors. The study also identifies measures for which there are insufficient studies to confirm or develop reliable estimates – particularly there are important gaps in the areas of: cooking, air compressors, ASD/VSD, refrigeration / freezers in some sectors, plug loads, building shells measures (which at least need verification), and a few others. These lack reliable study; EULs for some other measures have been estimated repeatedly. There has also been a trend toward simplified tables (e.g. one value across all business types), but this omits important turnover differences between business types, and investment differences between customer groups (e.g. the dramatically different replacement schedules for lighting between schools vs. restaurants).
- **Technical degradation**: The issue of technical degradation of equipment and its performance over time was discussed, and there is a shortage of primary research on this topic. The key question in energy efficiency evaluation is not whether technical degradation exists, but whether there is a

significant change in the pattern of the technical degradation for high efficiency equipment (that may be incentivized by programs) relative to the pattern for more standard efficiency equipment. If there is a difference, the savings patterns may differ; if not, the issue may be essentially ignored. Certainly, engineering-type studies can help to identify research priorities to some extent, noting which technologies have undergone engineering, mechanical, or process changes that will more likely significantly change their performance relative to standard equipment. However, equipment with significant changes in behavioral (operational or upkeep) elements may also see changes in performance. Priority-setting for new research on this topic should take both factors into account (mechanical and behavioral), and resulting figures should be verified periodically.

- **Remaining Useful Lifetimes (RUL) issues**: The issue of measure lifetimes – and the time over which the incremental savings should be counted or attributed to the program – becomes more complicated if the program targets early removal of operating devices. In this case, we might argue that the time between early removal and the point at which the equipment would otherwise have been replaced (potentially with something energy efficient) should receive savings equaling the difference between the energy use of the "old" equipment and the "new" equipment. At the point at which the equipment would have been replaced, the relevant "delta" in energy savings could revert to the traditional difference between the "new" efficient equipment and the "standard new" efficient equipment that would otherwise have been purchased (used for end-of-lifetime programs). The tricky element is that little research or data collection has been done to estimate the length of the early removal period, and thus, the analysis methods aren't well understood. Some studies proposed ad hoc figures (one third of the lifetime), but clearly, the program's design and targeting plays a role in the estimate. Perhaps in the short run, presenting benefit-cost figures including and excluding the enhanced savings could be presented to identify whether the programs are moving decisions forward enough to make a difference. A recent study (Welch and Rogers 2011) provides promising research on two estimation methods with practical options for estimating RULs for programs. For one estimation method, they used mortality data from a nationwide survey and developed Weibull distributions for the appliances of interest; and for the other, they modeled technology stock cohorts. Both showed good promise for applications beyond the appliances they modeled. Additional research is needed to explore the potential of these (or other) methods for expansion to other measures. The concept applies to behavioral programs as well (mandating changes in behavior / practices, or educating to bring future behaviors to the present) has value, but in this case, the modeling of behavior and lifetime cohorts may pose a particularly thorny research problem.
- **Retention or lifetimes of behavioral changes results and needs**: Of particular note is the virtual absence of studies addressing retention or persistence of education / outreach / behavioral programs. This is an important gap, as behavioral and market-based programs have become a larger and larger share of utility / agency portfolios. Further research in best practices for the array of behavioral programs or "types" would be a useful addition to the literature, and agencies should consider requiring new behavioral programs to conduct retention assessments every year or two for a period reaching on the order of three or more years out. This may be the only way to gain enough information to develop credible estimates of the persistence of savings from behavioral programs and to allow more serious consideration of them as reliable resource substitutes. The issue of retention of behaviors and savings for "upstream" education and training programs is particularly troublesome, and, to the degree that these programs are part of portfolios, retention work is needed where there currently is none. Finally, EUL measurement approaches will need to be tested and applied to a variety of behavioral programs. Some may parallel traditional EUL estimation best practices, but the application of statistical approaches to some programs may be challenging. EULs for behavioral programs will have to consider issues related to how to treat partial retention,[23] examine alternate measurement methods considering the potential short lifetimes of some programs, examine issues of frequency of data collection, retention of "upstream" behaviors, large surveys and random assignment, among other items not examined much to date in association with measure-based programs. This research should be a priority for the near term.

---

[23] A few members of a household keep the behavior but others don't- perhaps parallel to Technical Degradation in a measure.

Measure lifetimes are a key element in the computation of program savings. It is important to assure that new programs are developed – including creative programs and programs that encourage new measures and behaviors and are not the “same old same old”. However, if measure lifetimes, technical degradation factors, and other factors are known for some programs and unknown up front for others, there will be a bias away from developing new (more uncertain) programs. Risk is an issue affecting investment and development.

Risk needs to be considered from two perspectives – providing up-front information on computational elements encourages program development. “True-up” is needed for credibility and reliability of savings estimates for EE relative to generation capacity. One suggestion may be that new programs are assigned a deemed lifetime by general “type” up front, and then after 1-2 years, a true-up is prepared that does not readjust program incentives retroactively, but does refine the estimate of future savings from a resource perspective.

Identifying the lifetimes or EULs of behavioral or information programs is complicated as more media messages on behaviors and education bleed across territories. This affects retention of the messages and behaviors because behaviors originally attributable to the program may be “refreshed” from other sources. It may not be possible to separate these out cleanly; research is required to determine the extent of this problem. The priority depends on the ranking of estimated savings and costs from these programs. In addition, results on measure lifetimes, and any remaining useful lifetime (RUL) and technical degradation factor (TDF) research should be accumulated in a database and updated continuously so comparisons and tracking are facilitated.

Summary and Conclusions

As more behavioral programs are introduced, these issues – which are complicated and in some ways need refinement / updating even for current programs – will face even greater need for innovation and improvement. This paper summarized best practices to date, and identified gaps, promising tactics, and areas in need of additional research. The progress to date has been great, as represented by the 250-plus reports and articles reviewed for this study. However, continued creativity, innovation, and work are needed on an on-going basis. There are gaps – especially in the (growing) area of behavioral programs. New programs are conceived that don’t fit old molds. Marketplace “chatter” is not going to go away, so methods that can account for the interaction of influences from multiple programs and sources are an essential part of moving forward – or alternatively, we will need to decide that causation cannot be demonstrated clearly enough, and accept that our programs may need to get credit for being a key causal factor, rather than trying to attribute specific programs as sole or “driver” influences. The question of the “best” evaluation method for impacts, attribution, and retention of behavioral programs, will continue to be an evolving and moving target– the better to continue to challenge the creative minds in the energy, psychology, behavioral, market research, economic, engineering, statistical, and other fields that have been brought to bear on these topics.

References[24]

Baker, David S., 2008. Illinois Department of Commerce and Economic Opportunity, Energy Division. Interview with the author, November 20, 2008.

Bensch, Ingo, 3/31/09. Energy Center of Wisconsin, WI, Personal Communication with the Author.

Cooney, Kevin. 7/31/08. Summit Blue, Boulder, CO, Personal Communication with the Author.

Dimetrosky, Scott, Bicknell, Charlie, and Titus, Elizabeth. 2007. "Filling Gaps In The Story Of Energy-Efficiency Program Success: Evaluating the Availability of Market Penetration Tracking Data for the Residential Sector". AESP White Paper: March 2007

Drakos, Jamie, 3/31/09. Cadmus Group, Portland, OR, Personal Communication with the Author.

Gordon, Fred, 7/25/08. Oregon Trust, Portland, OR, Personal Communication with the Author.

[24] The long list of references underlying this project is cited in Skumatz 2009, the full report from which this article is excerpted.

Gordon, Susie, and Lisa A. Skumatz, 2007, "Integrated, Real Time (IRT), On-Going Data Collection For Evaluation – Benefits And Comparative Results (Gordon & Skumatz, 4323), Procee*dings for the European Council for an Energy Efficient Economy (ECEEE),* France, June.

Hedman, Brian. 3/31/09. Cadmus Group Portland, OR, Personal Communication with the Author.

Mahone, Douglas. 2008. Email from Douglas Mahone to Robert Kasman (PG&E), June 12, 2008, provided to author.

Messenger, Michael. 7/29/08 and 4/3/09. Itron, Sacramento, CA, Personal Communication with the Author.

Quantec, Scott Dimetrosky. 2008. "Assessment of Energy and Capacity Savings Potential in Iowa", Prepared for the Iowa Utility Association, February 15, 2008.

Ridge, Richard, Phillipus Willems, Jennifer Fagan, and Katherine Randazzo. 2009. "The Origins of the Misunderstood and Occasionally Maligned Self-Report Approach to Estimating the Net-To-Gross Ratio", *Proceedings of the IEPEC Conference*. Portland, Oregon, August.

Saxonis, William. 2007. "Free Ridership and Spillover: A Regulatory Dilemma", *Proceedings of the IEPEC Conference*, Chicago Illinois, August.

Skumatz, Lisa. 2006. "Tracking Market Progress: Addressing Traditional Measurement Flaws with an Innovative Proxy -the "NEEPP" Tracking Approach", AESP White Paper: January 2007.

Skumatz, Lisa A., 2009. "Lessons Learned and Next Steps in Energy Efficiency Measurement and Attribution: Energy Savings, Net to Gross, Non-Energy Benefits, and Persistence of Energy Efficiency Behavior", prepared for CIEE, December. Available at: http://uc-ciee.org/energyeff/energyeff.html.

Skumatz, Lisa, Dan Violette, and Rose A. Woods, 2004. "Successful Techniques for Identifying, Measuring, and Attributing Casualty in Efficiency and Transformation Programs." *Proceedings of ACEEE Conference*, Asilomar, CA.

Sulyma, Iris M., Power Smart, BC Hydro, Vancouver, Canada, Personal Communication with the Author, 4/28/09.

Train, Kenneth, UC Berkeley and N/E/R/A, CA, Personal Communication with the Author. 10/6/09.

Welch, Cory and Brad Rogers, 2011, "Estimating the Remaining Useful Life of Residential Appliances", Proceedings of the AESP Conference, Orlando, FL, January.

Danish Home Energy Check – an Innovative Tool to Help Home Owners Consolidate their Knowledge about Energy Efficiency in their Homes

Henrik Teglgaard Lund

Head of Secretariat, Danish Energy Saving Trust

Abstract

There is a huge potential for saving heat in homes, but using the services of an Energy Labelling Consultant to identify possible savings is an expensive business. Home owners and renters are very knowledgeable about their homes, but they do not have access to tools that can convert this knowledge into savings actions.

This paper describes how the Danish Energy Saving Trust has developed and is now expanding its 'Boligtjek' (Home Energy Check), a web-based tool to identify potential energy improvements based on information from Danish public registers and factual input by owners/renters. The paper describes how the tool will ultimately convert the information supplied, and the underlying calculations, into a dynamic energy label which automatically adjusts when the user makes energy efficiency improvements in the home.

The core component of the Home Energy Check calculator is the calculation model from the Danish Building Research Institute, which has been developed to calculate and document the heating requirements for new buildings. Home Energy Check adds statistical details about the home to the calculations, supplemented by information supplied by users on the energy consumption and the conditions in their homes. Home Energy Check provides a realistic evaluation of the potential savings and makes recommendations for reducing the energy consumption. The system updates the list of suggested improvements in line with changes inputted by the householder.

Hopefully, Home Energy Check will motivate home owners/renters to analyse the energy-related conditions in their homes, making the tool a user-friendly and non-binding way of acquiring knowledge and information about energy efficiencies in the home. We anticipate that Home Energy Check will lay the foundations for a dynamic energy label that provides users with an estimate of the future energy label of their building. We also expect the tool being used by Energy Labelling Consultants during the course of their work.

Introduction

European consumers can save billions of Euros – simply by making sure that appliances in their homes only consume electricity when actually in use, and by having the most efficient heating system and efficient building envelope. The secret is to eliminate unnecessary consumption and ensure that lighting, ventilation, heating systems and air conditioners are only switched on when required.

Nevertheless, if homes are to be heated, and electricity consumption reduced in the years ahead, it is not enough to rely on behavioural campaigns and increased taxes on energy. We also need to introduce smart concepts which will facilitate the identification of weak points in individual homes and ensure the implementation of the right solutions in a cost-effective manner.

In the light of the experiences gained from the former Danish Electricity Saving Trust's[1] My Home concept [1], the new Danish Home Energy Check platform attempts to address these issues by providing users with an easy-to-use interface that identifies energy wasteful products, suggests more efficient alternatives, and encourages a greener lifestyle.

[1] The Danish Energy Saving Trust (Go' Energi) is expanding the activities of the former Danish Electricity Saving Trust (Elsparefonden) and is now responsible for promoting savings for all forms of energy, excluding transport, in the household, public and industrial and commercial sectors. Established on 1 March 2010, the Trust is an independent, public sector organisation with its own Board appointed by the Minister for Climate and Energy.

In particular, there is a huge potential for saving heat in homes, but using the services of an Energy Labelling Consultant to identify possible savings is an expensive business. Home owners and renters are very knowledgeable about their homes, but they do not have access to a tool that can convert this knowledge into savings actions.

The Trust is therefore developing and expanding its new Danish Home Energy Check electricity saving tool to also cover heating. The Home Energy Check tool (known as “Boligtjek” in Danish) identifies potential energy improvements based on information in the Danish public registers [2] combined with input about individual homes supplied by owners/renters.

This paper looks at the background and strategy for the Danish Energy Saving Trust’s initiatives for saving energy in homes and buildings, and describes how Home Energy Check will be an element in the strategy of making it easy to save energy. The paper goes on to outline the overall concept, and focuses on the heating area and the calculation logic underlying the potential energy improvements suggested by the Home Energy Check program. The paper also details how the program converts the inputted information and knowledge into actual savings suggestions using a specially adapted version of the Danish Building Research Institute's professional tool for calculating and documenting the heating requirements of a building.

Strategy on saving energy in buildings

The key plank of the Danish Energy Saving Trust's overall activities is to break the upward curve of Denmark's gross energy consumption, thereby reducing the country's dependency on fossil fuels, and minimising the impact on the climate and the environment. In this respect, the Trust's overriding strategy is to ensure this happens by 'making it easy' to save energy at all levels of society by helping the different target groups to adopt energy efficient solutions. The Trust will structure its work with the aim of reducing the barriers that prevent, or delay, the implementation of financially attractive and viable energy projects.

Energy consumption and saving potentials

The total amount of energy consumed by Danish end-users in 2008 amounted to 441 PJ [3]. The consumption breakdown for homes, manufacturing industry, and the commercial and the public sectors is illustrated in Figure 1:

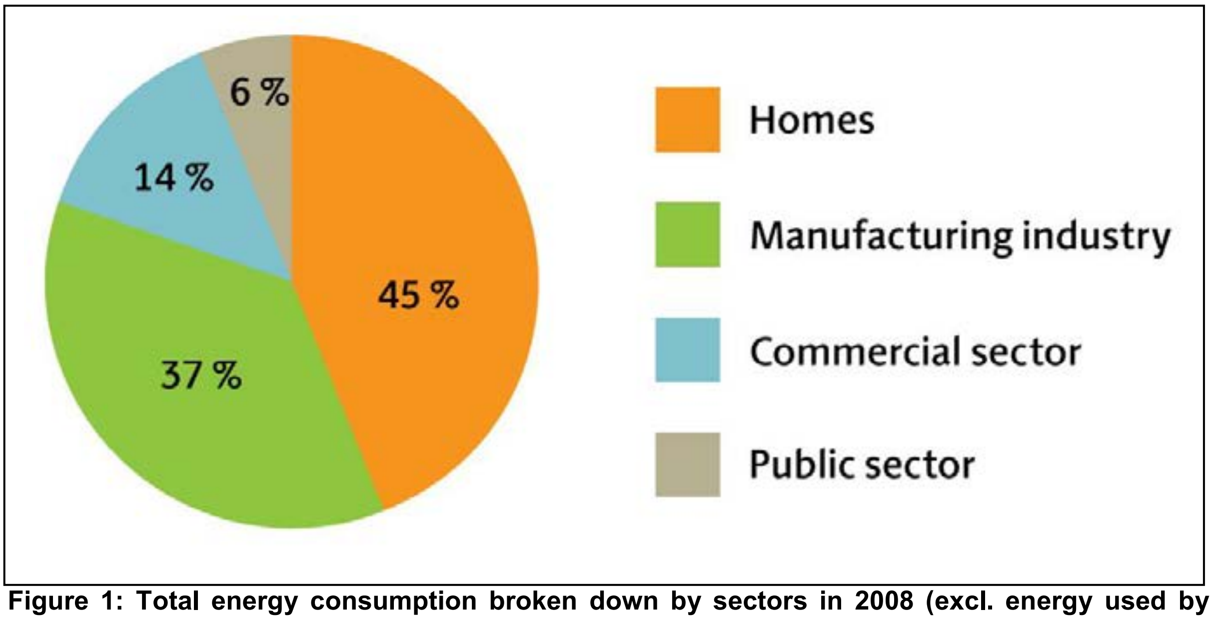


Figure 1: Total energy consumption broken down by sectors in 2008 (excl. energy used by transport) comprises both electricity and other forms of energy with different costs and environmental impacts [4].

If you examine the development of energy consumption in Denmark over the past 10 years more closely, and the breakdown of energy consumption by different end uses, a distinctive pattern emerges. Energy consumption in homes is easily the biggest item – even larger than consumption by manufacturing industry – and although consumption has stagnated since about 2005, it had been rising continuously before that. Room heating accounts for by far the largest share of total consumption.

New campaign in 2011

In 2011, the Trust's activities will mostly focus on energy improvements in buildings, which have been earmarked as a special strategic area of initiative. There is a large unused potential for improving the energy efficiency of buildings, especially within the existing stock of buildings.

This applies across all target groups, from private homes to large offices and other commercial and industrial buildings. At the same time, this is an area on which there has not been much focus in national campaigns. Many people still have the impression that it is generally an expensive and difficult process to make serious alterations to the building envelope, and to heating installations in private homes.

Together with other actors, there are many barriers that the Trust needs to reduce. These include making energy users aware of the possibilities for improvements; providing them with individually targeted information, valuable advice and possible technical solutions; presenting them with realistic information about the savings opportunities and the financial consequences; putting them in touch with qualified tradesmen and firms that can fulfil the required tasks; arranging for the necessary finance to be in place; and getting help with managing projects from conception to completion.

The Trust needs to go on the offensive to tackle all these challenges and provide energy users with as much support as possible to take their projects further. In this way the Trust is helping to stimulate a lot of interest in carrying out projects that improve energy efficiency [5].

Role of Home Energy Check in the campaign

The role of Home Energy Check in the building campaign is to lead users closer to the goal of achieving energy savings. The first step is to alert users to the potential for saving heat in their homes. This message was conveyed in a TV campaign on saving heat in buildings, supplemented by a print media campaign. The campaign made people aware of the potential, and motivated them to take a closer look at their actual energy consumption.

Once users have got hold of the basic idea, and understand that it may be possible to unlock potential heat savings, the next step involves steering them in the direction of the web universe. Once there, the aim is to activate them, and increase their level of awareness. One of the ways of doing this is to identify the areas in their homes which would typically require action in order to minimise heating bills. This can be done in a general sense, but we also give users the opportunity to answer a few questions about their homes and habits, followed by a message that they should research the potential further on Home Energy Check.

Thereafter, users are transferred to Home Energy Check. At this point, users have already been exposed to the idea of Home Energy Check and to their potential savings, increasing the likelihood that they will be interested in identifying specific problems with the help of Home Energy Check

Concept

Overall Concept

Home Energy Check provides users with rapid access and easily understood knowledge about the potential energy savings in their homes. The program provides calculations for both electricity and heating, with the latter accounting for a significant amount of the energy used in Danish homes.

Initial screening.

When a user visits the Home Energy Check website, he or she is asked to input their address, which is screened to establish whether it is covered by an energy label [6]. Today, about 200,000 Danish homes are energy labelled, and the home's energy label and corresponding energy labelling report (if available) are shown to the user. The report contains savings suggestions prepared by an energy consultant, giving the user an idea of what can be done to improve the home's energy consumption.

Subsequently, the users are directed into different channels, depending on whether they live in a house, flat or holiday home. The program focuses on electricity for users who live in a flat. Because individual owners of the flats often have very little direct influence on the building envelope, and are therefore less motivated personally and financially, the following sections mostly focus on the channel for home owners.

Potential savings

Home owners are presented with a 3D illustration of their home and a list of possible savings which can involve changes to habits, and improvements to the building envelope or installations. The savings are based on the existing knowledge available from the public registers about the specific house in question, and how this compares with knowledge and information about similar types of homes. Figure 2 shows the front page.

Figure 2. The 'Boligtjek' front page with menu of available choices, and tabs for suggestions (VI FORESLÅR) and savings areas (ALLE BESPARELSER).

The savings are calculated on the basis of a calculation tool from Danish Building Research Institute combined with statistical material on the house type and construction periods. All this information is presented to users in layers that reflect the gaps in the calculations. To get a more accurate calculation, users can provide specific information about their own homes, which replaces the basic statistical information. The more information provided, the more precise the calculations become.

Users can also make the details more precise by using a built-in drawing programme as shown in Figure 3. This allows users to input information about complex situations in a straightforward way, where users are constantly able to view their homes in ever greater detail.

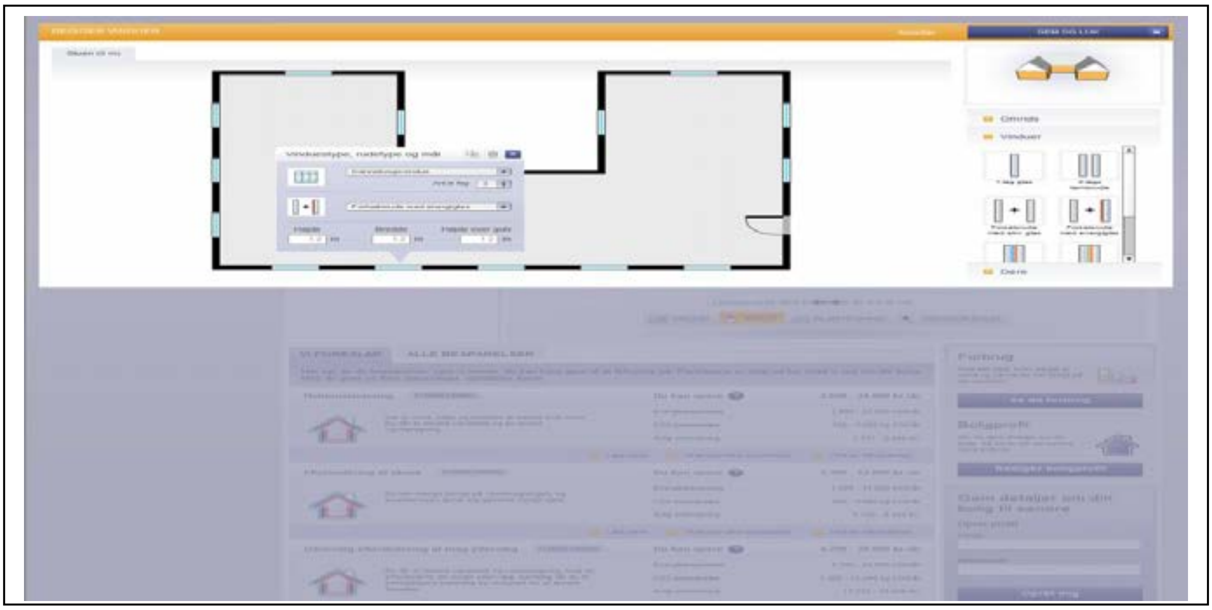


Figure 3. The 'Boligtjek' drawing tool allows users to draw a floor plan of their home.

Implementing savings

All the suggested improvements and suggested changes to installations are presented along with an estimate of how much it will cost to achieve the savings. The prices are sourced from a price database [7] which contains information and prices from the construction sector for materials, wages, products, working hours, etc. In situations where the energy improvements are financed by a loan, the total cost will be higher. This reflects the interest payable over the term of the loan.

Once users have a clear idea of the potential energy savings in their homes, the next step involves putting some of these savings into practice. At this point users can choose to continue to the Trust's list of qualified tradesmen, where they will find the names of recommended tradesmen who can carry out the improvements to achieve the required heating efficiencies.

Energy labelling of buildings

Homes are typically energy labelled when they are put on the market, with the home assessed by an energy consultant who prepares an energy label report. This report provides details of the condition of the building, and establishes which energy label the building has, and which improvements the home owner should undertake to minimise the consumption and maximise the efficiency. The report also includes an estimate of the costs and the savings achieved by the different energy improvements.

In the foreseeable future, Home Energy Check will incorporate the official energy label. In this way Home Energy Check will both explain precisely which energy label already officially applies to the home, as well as converting the changes to the building envelope and installations into a new unofficial energy label. The result will thus be a dynamic energy label that changes in keeping with input from users.

In addition, the concept is fully integrable with the building's energy label, where energy label recommendations can be implemented in Home Energy Check, thereby providing users with a breakdown showing which recommendations derive from the energy label, and which recommendations come from Home Energy Check.

Energy consultants involved with the energy labelling of buildings will also benefit from using Home Energy Check, through being able to get an insight into the building before visiting, and through being able to see which improvements home owners/tenants have carried out since the last energy label survey. When selling the house a user can even transfer the building to another owner who can attach the home to his private Home Energy Check profile, letting valuable information live on.

Calculation basis for heating efficiency

Making realistic calculations of the potential savings in a house is a complex process. There are a large number of conditions which need to be taken into account in order to obtain an accurate picture of the savings possibilities. The actual energy consumption of a building is influenced by the quality and maintenance of the building and its installations, by the location and orientation of the building, and by the habits and behaviour of the building's occupants.

Home Energy Check is based on the calculation model from the Danish Building Research Institute , which is an officially recognised tool developed to calculate the heating requirements in a building. When this calculation is supplemented with statistical information about the actual house type and its age, and with specific information inputted by the householder, Home Energy Check is able to provide actual suggestions for changes that will result in energy efficiencies.

Data for the calculations

The Danish public registers contain data on a building's location, its use, year of construction, dates of extensions/alterations, conservation orders applying, numbers of floors, size (building plot size, building area, etc.), types of construction materials (external walls, roof, etc.), and heating installations (primary and secondary forms of heating). These data are linked to reference values from the Danish Building Research Institute in relation to the year in which the building was constructed. The reference values are based on the mapping of the statistical energy condition of the building in respect of the year in which it was constructed, together with the improvements that are typically undertaken over subsequent years.

Assumptions and user information

Based on these data we make a number of assumptions about the home and provide a qualified estimate of its condition. We use this estimate to arrive at several key suggested improvements which can reduce a homeowner/renter’s heating bill. One example of an important assumption is the overall area of the windows, which has a major influence on heating consumption. In this situation we estimate the area and ask users to correct the information if the actual situation differs from the estimate.

The savings calculations provided to a home owner/renter can vary a lot depending on the form of heating used, and the actual condition of the house and the consumption level. For this reason, one of the first things that users are asked is to provide their actual heating consumption and details of their heating installations. This information has a major influence on how great the savings will be, and which savings are relevant.

Savings level – low energy

The savings suggested by Home Energy Check are calculated so that users obtain a "low energy" savings level for their building. This is the equivalent to the requirements set for new construction. This level was chosen because it should communicate to users that it is often worthwhile implementing comprehensive solutions when undertaking renovations.

Accuracy of the calculations

As stated above, users are able to add extremely detailed information about their homes. The information provided is primarily used in the calculations, but is also used to indicate how precise the calculations are. A "global %" box shows users how much we know about them, their home, and about their consumption. Depending on the type of building and its age, the different parameters are calculated separately. However, the primary rule is that the greater the % filled in, the more precise the calculations will be. This applies equally to the savings and cost intervals, which become narrower as more information is supplied. However, it is worth noting that the calculations will always be displayed as an interval, and never a single number.

Conclusion

Home Energy Check motivates users very directly to implement energy efficiencies in their homes by demonstrating to them how much can be saved. But the program also provides indirect value by increasing the knowledge consumers have about energy savings in general. This increased knowledge will mean that at some point in the future users can take more informed decisions when the time comes to renovate their homes.

The main reason for developing and expanding Home Energy Check was to increase the user value of the Trust's previous My E-Home offering by lowering the demands, and the contribution that users previously needed to make, so as to appeal to a wider target group. Irrespective of the ambition level, users are now able to get information on energy savings easily and without obligation, as well as receiving a rapid assessment of the scale of potential energy savings in their homes.

Through the use of a professional calculation model combined with a comprehensive knowledge base, we can offer users valuable knowledge and realistic calculations – even in situations where users have merely inputted an address. The benefit of providing a quick estimate is that the savings identified can motivate users to go further by providing specific information about themselves, and their consumption and homes, thereby getting a more precise estimate of potential savings. In this way, users have a good basis for deciding to invest in energy efficiencies.

By linking the potential energy savings to the cost of implementing the savings, we are also providing even better motivation to take decisions on improvements. This is why it is important to make specific recommendations about tradesmen who can implement solutions to save heat via the Trust's list of qualified tradesmen.

In the future, we expect that the Danish Home Energy Check will become an important tool for all home owners who, with a little effort on their part, will receive a summary of the potential energy savings in their homes. The key point about Home Energy Check is that it can be used by everyone for free. This means that home owners/renters can begin to work actively on energy efficiencies for the building envelope, even in situations where the property is not being sold.

References

[3], [4] Danish Energy Agency. Energy Statistics 2008. http://www.ens.dk/DA-DK/FORBRUGOGBESPARELSER/ENERGISPAREPOLITIK/EVALUERINGAFENERGISPAREINDSATS/Sider/Forside.aspx (only in Danish)

[6] Danish Energy Agency, EU Energy Performance of Buildings Directive (the EPDB): http://www.ens.dk/da-DK/ForbrugOgBesparelser/IndsatsIBygninger/Energimaerkning/Sider/Energimaerkning.aspx (only in Danish)

[2] Data from the Danish National Survey and Cadastre and Register of Buildings and Homes (Kort og Matrikelstyrelsen og Bygnings- og Boligregistret): https://www.ois.dk (only in Danish)

[4] Sekretariatet for Energieffektive Bygninger (Danish Secretariat for Energy Efficient Buildings), http://www.seeb.dk (only in Danish)

[7] The Danish Building Information Centre, Price database: http://www.byggecentrum.dk/?id=1327 (only in Danish)

[6] The Danish Building Research Institute, http://www.sbi.dk/

[5] The Danish Energy Saving Trust (2011): Handlingsplan 2011 http://www.goenergi.dk/publikationer/handlingsplaner (only in Danish)

[1] Wilke, Göran, (2009): My Home – analysis of the easy and intelligent way to save energy, Paper 4190, Eceee Summerstudy 2009.

European Commission
EUR 26492 – Joint Research Centre – Institute for Energy and Transport

Title: Proceedings of the 6th International Conference EEDAL 11 Energy Efficiency in Domestic Appliances and Lighting

Authors: Gueorgui Trenev, Paolo Bertoldi

Luxembourg: Publications Office of the European Union

2013 – 1256 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-35418-2 (pdf)

doi: 10.2790/14411

Abstract:

This book contains the papers presented at the sixth international conference on Energy Efficiency in Domestic Appliances and Lighting. EEDAL'11 was organised in Copenhagen, Denmark in May 2011. This major international conference, which was previously been staged in Florence 1997, Naples 2000, Turin 2003, London 2006, Berlin 2009 has been very successful in attracting an international community of stakeholders dealing with residential appliances, equipment, metering and lighting (including manufacturers, retailers, consumers, governments, international organisations and agencies, academia and experts) to discuss the progress achieved in technologies, behavioural aspects and policies, and the strategies that need to be implemented to further progress this important work.

Potential readers who may benefit from this book include researchers, engineers, policymakers, and all those who can influence the design, selection, application, and operation of electrical appliances and lighting.

LD-NA-26492-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

Publications Office

DOI 10.2790/14411
ISBN 978-92-79-35418-2