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PORTUGAL SB13

CONTRIBUTION OF SUSTAINABLE BUILDING TO MEET EU 20-20-20 TARGETS

30 Oct > 1 Nov | 2013 | Guimarães | PORTUGAL

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PORTUGAL SB13

CONTRIBUTION OF SUSTAINABLE BUILDING TO MEET EU 20-20-20 TARGETS

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PORTUGAL SB13

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Foreword

The international conference Portugal SB13 is organized by the University of Minho, the Technical University of Lisbon and the Portuguese Chapter of the International Initiative for a Sustainable Built Environment in Guimarães, Portugal, from the 30th of October till the 1st of November 2013.

This conference is included in the Sustainable Building Conference Series 2013-2014 (SB13-14) that are being organized all over the world. The event is supported by high prestige partners, such as the International Council for Research and Innovation in Building and Construction (CIB), the United Nations Environment Programme (UNEP), the International Federation of Consulting Engineers (FIDIC) and the International Initiative for a Sustainable Built Environment (iiSBE).

Portugal SB13 is focused on the theme “Sustainable Building Contribution to Achieve the European Union 20-20-20 Targets”. These targets, known as the “EU 20-20-20” targets, set three key objectives for 2020:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency.

Building sector uses about 40% of global energy, 25% of global water, 40% of global resources and emit approximately 1/3 of the global greenhouse gas emissions (the largest contributor). Residential and commercial buildings consume approximately 60% of the world’s electricity. Existing buildings represent significant energy saving opportunities because their performance level is frequently far below the current efficiency potentials. Energy consumption in buildings can be reduced by 30 to 80% using proven and commercially available technologies. Investment in building energy efficiency is accompanied by significant direct and indirect savings, which help offset incremental costs, providing a short return on investment period. Therefore, buildings offer the greatest potential for achieving significant greenhouse gas emission reductions, at least cost, in developed and developing countries.

On the other hand, there are many more issues related to the sustainability of the built environment than energy. The building sector is responsible for creating, modifying and improving the living environment of the humanity. Construction and buildings have considerable environmental impacts, consuming a significant proportion of limited resources of the planet including raw material, water, land and, of course, energy. The building sector is estimated to be worth 10% of global GDP (5.5 trillion EUR) and employs 111 million people. In developing countries, new sustainable construction opens enormous opportunities because of the population growth and the increasing prosperity, which stimulate the urbanization and the construction activities representing up to 40% of GDP. Therefore, building sustainably will result in healthier and more productive environments.

The sustainability of the built environment, the construction industry and the related activities are a pressing issue facing all stakeholders in order to promote the Sustainable Development.

The Portugal SB13 conference topics cover a wide range of up-to-date issues and the contributions received from the delegates reflect critical research and the best available practices in the Sustainable Building field. The issues presented include:

- Nearly Zero Energy Buildings
- Policies for Sustainable Construction
- High Performance Sustainable Building Solutions
- Design and Technologies for Energy Efficiency

- Innovative Construction Systems
- Building Sustainability Assessment Tools
- Renovation and Retrofitting
- Eco-Efficient Materials and Technologies
- Urban Regeneration
- Design for Life Cycle and Reuse
- LCA of sustainable materials and technologies

All the articles selected for presentation at the conference and published in these Proceedings, went through a refereed review process and were evaluated by, at least, two reviewers.

The Organizers want to thank all the authors who have contributed with papers for publication in the proceedings and to all reviewers, whose efforts and hard work secured the high quality of all contributions to this conference.

A special gratitude is also addressed to Eng. José Amarílio Barbosa and to Eng. Catarina Araújo that coordinated the Secretariat of the Conference.

Finally, Portugal SB13 wants to address a special thank to CIB, UNEP, FIDIC and iiSBE for their support and wish great success for all the other SB13 events that are taking place all over the world.

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Vítor Ferreira
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Contents

Chapter 6: Building Sustainability Assessment Tools

Chapter 7: Renovation and Retrofitting

Chapter 8: Eco-Efficient Materials and Technologies

Chapter 9: Urban Regeneration

Chapter 10: Design for Life Cycle and Reuse

Chapter 11: LCA of sustainable materials and technologies

Chapter 12: Thematic Session - Smart Regions: which strategies?

Chapter 1

Nearly Zero Energy Buildings

Cost optimal building renovation with a net zero energy target for the Portuguese single-family building stock built before 1960

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ABSTRACT: Cost Optimality and nearly Zero Energy Buildings (nZEB) are two fundamental concepts within the current European Union policy related to the energy performance of buildings and consequently related to climate change mitigation and non-renewable resources consumption. While Cost Optimality is mainly focused on costs, nZEB are focused on low energy consumption levels and on site renewables harvesting.
If the differences between Cost Optimality and nZEB approaches result in major differences in the selection of the best package of renovation measures, the transition from the Cost Optimal concept to nZEB might result incompatible. In this context, using a virtual building representing the Portuguese residential building stock from the 20th century prior to 1960, this study investigates the most cost-effective packages of renovation measures to achieve a zero energy balance building and compares these packages with those resulting from the calculation of cost-optimal levels.
Investigating the trade-offs between a renovation towards zero energy balance and a cost optimal renovation without the use of renewables is relevant to achieve a smooth transition from Cost Optimal levels to nearly Zero Energy Buildings.

1 INTRODUCTION

Climate change observed on the planet is taking an increasingly important role on the society, thus requiring an urgent response at global level (European Commission, 2006).

Since buildings account for about 40% of energy consumption in the European Union, this sector has become an important target for interventions to reduce the greenhouse gases that are released into the atmosphere (European Commission, 2012a).

Within this context, the concept of nearly zero energy buildings arose in the European energy policy as a tool to deal with the need of independence from fossil energy sources and external energy supply (European Parliament, 2010). Energy efficiency and energy harvesting from renewable sources on site or nearby are the essential elements that from the year 2020 on will allow that all new buildings will be nearly zero energy buildings (NAIMA, 2011). However, the long term goals of reducing energy consumption in the European Union for the year 2050 (European Commission, 2011) are impossible to achieve without interventions on the building stock given the very low rate of replacement of the existing buildings by new ones.

The recast of the Energy Performance of Buildings Directive (European Parliament, 2010), besides the definition of Nearly-Zero Energy Buildings, introduced the concept of Cost Optimal levels, which will pave the way of the new energy codes in all EU Member States and their building sector. The concept of Cost Optimal levels is intended to guide Member States on establishing minimum energy performance requirements based on the costs during the entire building life cycle (European Commission, 2012a, 2012b) as opposed to just consider the initial investment cost.

In this context, this paper aims at analyzing the most cost-effective packages of renovation measures to achieve a zero energy balance building and compare these packages with those resulting from the calculation of cost-optimal levels for a typical building representative of the Portuguese housing stock built before 1960. Investigation of the trade-offs between a renovation towards zero energy balance and a cost optimal renovation without the use of renewables is relevant to achieve a smooth transition from Cost Optimal levels to nearly Zero Energy Buildings.

2 METHODOLOGY FOR THE CALCULATION OF COST OPTIMAL LEVELS

The economic viability of a building renovation towards a zero energy balance (for heating, cooling and domestic hot water (DHW) preparation) was determined according to the cost optimal methodology presented by the European Union (European Commission, 2012a).

In order to obtain the cost optimal level for a building renovation it is necessary to test different packages of renovation measures to improve the energy performance of the building and calculate the associated energy needs, the costs to implement those measures and the running costs during the remaining life span of the building.

These packages of measures should be chosen considering that measures applied in a given building element or system can affect the energy performance of other systems. This happens for example when considering different levels of insulation, for which higher insulation means lower heating needs and thus smaller heating devices.

Once defined and calculated the results for each renovation package, it is possible to build a graph based on the use of primary energy and the overall costs associated with the various energy efficiency measures. In this graph a costs curve is created, with the lower points of the curve indicating the packages of measures with the lowest global costs considering the investment costs and the running costs over the entire building life cycle, as demonstrated in Figure 1.

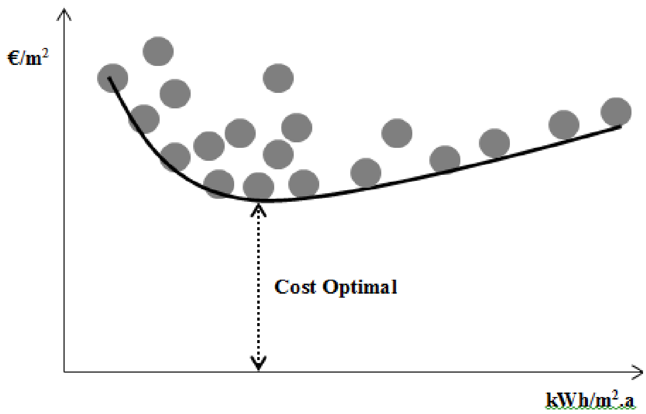

Figure 1 – Cost optimality

Then, with the final goal of obtaining variants of the building with zero energy balance, measures for the use of renewable energy sources are tested. The primary energy use of each variant is balanced with renewable energy and thus allowing to calculate and compare the overall costs associated with each renovation package in order to get the lowest global cost over the building lifecycle.

3 THE CASE STUDY

The building under analysis is representative of the Portuguese residential building stock from a period where energy efficiency was not a concern.

Different efficiency measures in the building envelope and different systems for HVAC and DWH were tested, evolving the building to better energy performance levels and subsequently introducing on-site renewable energy systems (RES).

3.1. Characterization of the reference building

The object of this study is a virtual building that represents the Portuguese existing buildings from the 20th century built before 1960. This building was created based on the data available in the database of the Energy and Indoor Air Quality in Buildings National Certification System (SCE), namely on the dimensions and geometry, construction materials and HVAC and DHW systems. For the location it was assumed the district of Braga, more specifically Guimarães at an altitude of 200 meters.

The selection of the most frequent characteristics of the buildings from this period led to a virtual building that is a single family house with 3 bedrooms consisting of a basement and a ground floor with 80m^2 and floor to ceiling height of 2.7m. Typically the building has lightweight slabs; non-heated attic covered by a wooden roof with ceramic tiles, 50cm thick stone masonry walls with plaster on both sides and windows with wooden frames and single glazing.

The building presents four facades, N, S, E and W oriented, having an average width of 8.94m^2 per facade, a total area of facades of 96.55 m^2 and a total area of glazing of 12m^2, which represents about 12% of the building envelope.

Usually these buildings do not have any insulation, and make use of some simple systems for heating, cooling and preparing hot water. Commonly for DHW preparation a gas water heater is used and electric appliances as fans and electric heaters are used for cooling and heating. Thus, the building presents annual nominal global needs of primary energy in the range of 712kWh/m^2.y to fulfill all the energy needs of the building for heating, cooling and DHW. For this study, the energy needs were calculated following the Portuguese thermal code methodology (Portugal, 2006) and the primary energy use was calculated considering the total energy needs and conversion factors of 2.5kWh$_{PE}$/m^2.y per kWh/m^2.y for electricity and 1kWh$_{PE}$/m^2.y per kWh/m^2.y for gas.

3.2. Identification of different energy efficiency measures

The measures tested were current renovation measures in the Portuguese market that are targeted to improve buildings energy efficiency. Thus, 96 different packages of measures were created by changing various factors such as insulation levels and window types, which were combined with six different HVAC and DHW systems.

At the level of the building envelope, various measures that increased the level of thermal insulation were tested. Outer walls measures are based on the application of ETICS system with a polystyrene (EPS) layer with thicknesses that vary from 30mm up to 140mm.

For the roof, it was considered the application of an insulation layer over the slab. The insulation material considered was extruded polystyrene (XPS) and polyisocyanurate (PIR) with various thicknesses (XPS varying from 30 up to 160mm and PIR varying from 80 up to 140mm).

In the basement ceiling, insulation measures included XPS with dimensions varying between 30 to 160mm and PIR varying from 30 to 80mm.

Regarding the windows, new PVC window frames with double glazing and thermal transmission coefficient of 2.00 W/m°C were taken into consideration.

In each package of measures different systems for HVAC and DHW with different efficiency and energy sources were used, such as two heat pumps, one with COP 4.1 and EER 4.0 and another with COP 3.33 and EER 2.68, both for heating, cooling and DHW. Other solutions included HVAC with COP 4.10 and EER 3.50, gas water heater with an efficiency of 86% and an electric water heater with efficiency of 80% both for DHW and a gas boiler with efficiency of 93% for heating and DHW.

Regarding on-site RES, three solutions were tested, namely a biomass boiler with efficiency of 92%, solar thermal collectors and photovoltaic panels for electricity generation.

3.3. Calculation of the global costs

The calculation of the investment costs was done based on a database with the true market values and thus obtaining prices that were comparable with the currently in practice by Portuguese companies. This database is provided by CYPE, SA (http://www.geradordeprecos.info/) and allows obtaining construction costs taking into account the values of all materials as well as the costs associated with installation, removal and maintenance.

Regarding the costs of energy and carbon emissions, the values published by the European Union (http://ec.europa.I/energy/observatory/trends2030/indexen.htm) and the 2010 scenario of the International Energy Agency for the gas were assumed (http://www.worldenergyoutlook.org/publications/weo-2010/). For the costs associated with the price of pellets for the biomass boiler, it was considered the current market price with a future increase of 3% per year. Table 1 presents the costs associated with each source of energy and the production of CO_2 used throughout this study.

Table 1 – Energy and carbon emissions costs

Energy prices (without and with taxes) and CO_2	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Electricity (€ cents per kWh)	21	21	22	22	23	23	24	24	24	25	25	25	26	26	26	26	26	26	26	26	26	26	25	25	25	25	25	24	24	24	24
Gas (€ cents per kWh)	7	8	8	8	9	9	9	9	9	10	10	10	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11
CO_2 (€ per ton.)	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*35*	*35*	*35*	*35*	*35*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*

For the calculation of the overall costs associated with each variant, a discount rate of 6% was used, as suggested by the European Commission (European Commission, 2012a).

3.4. Cost optimal calculations

Analyzing the different renovation packages, those with the lowest global costs within each group of building systems for heating, cooling and DHW preparation have been identified.
Figure 2 shows the global costs and the non-renewable primary energy associated to each renovation package. In Figure 2, each mark represents a different renovation package.

Figure 2 demonstrates that the package of measures with the lowest global costs is associated with the use of a gas boiler for heating and DHW preparation. Although these packages of measures, as well as those with the biomass boiler are not able to provide cooling, the introduction of an equipment only to deal with cooling needs is not usual in residential Portuguese buildings and the low cooling needs that are experienced in most of the country makes such an investment generally unjustified.

Considering the package of measures with systems that also deal with active cooling, the lowest costs are found with the use of a multi-split HVAC system for heating and cooling and a gas heater for DHW preparation. The use of heat pumps lead to low non-renewable primary energy use, but their initial costs compromise their economic performance even considering the entire life cycle of the building. However, attention should be paid to the fact that the two most cost effective packages of systems for HVAC and DHW require the availability of the natural gas grid, which doesn't cover all areas of the country. If natural gas is not available, the packages of measures using the multi-split HVAC system combined with electric heater for DHW, the biomass boiler and the heat pump with COP 4.1 and EER 4.0, all present very similar global costs with huge differences in the non-renewable primary energy use (128kWhm^2.a for the HVAC, 56kWhm^2.a for the heat pump, and 0kWh/m^2.a for the biomass boiler).

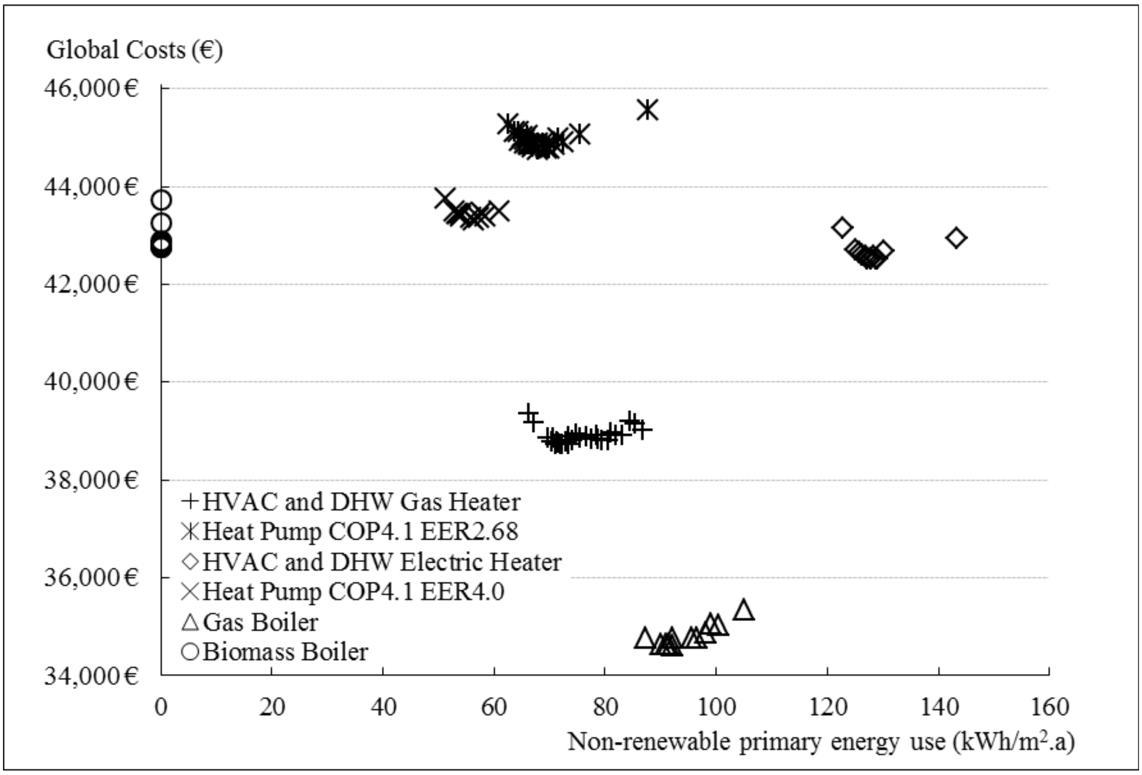

Figure 2 – Cost optimality evaluation without costs or energy restrictions

3.4. Impact of renewables on the cost effectiveness of HVAC and DHW systems

After this analysis, the use of on-site RES has been tested, with the introduction of a solar thermal system to reduce the energy needs to prepare DHW and photovoltaic panels to generate electricity in a quantity that equals the non-renewable primary energy use and thus, transforming the renovated building into a building with a zero non-renewable primary energy use for heating, cooling (when provided) and DHW preparation.

The contribution of the thermal solar system was calculated with the SOLTERM 5.0 software and the calculation of the photovoltaic power (kWp) required to generate the needed electricity was calculated using the online tool PVGIS (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php #), made available by the European Union, which takes into consideration factors such as the orientation of the photovoltaic panels, the slope and the location.

In Figure 3, the various packages of measures with a zero non-renewable primary energy use are presented associated to their global costs. Figures 2 and 3 shows that the hierarchy of cost effectiveness from the several HVAC and DHW systems didn't suffer major modifications with the use of on-site RES. Only for the two solutions using multi-split HVAC for heating and cooling a relevant approximation happens. In fact, with on-site RES, the use of an electric heater or a gas heater for DHW becomes almost equivalent, certainly due to the significant reduction of energy needed to increase the water temperature by the effect of the solar thermal system.

Again with the exception of the strong effect in the DHW system using an electric heater, also the differences in global costs between the several HVAC and DHW systems are similar with those obtained in the analysis without on-site RES.

Considering these results it is possible to conclude that the installation of on-site RES doesn´t change significantly the hierarchy of cost effectiveness between the different HVAC and DHW systems.

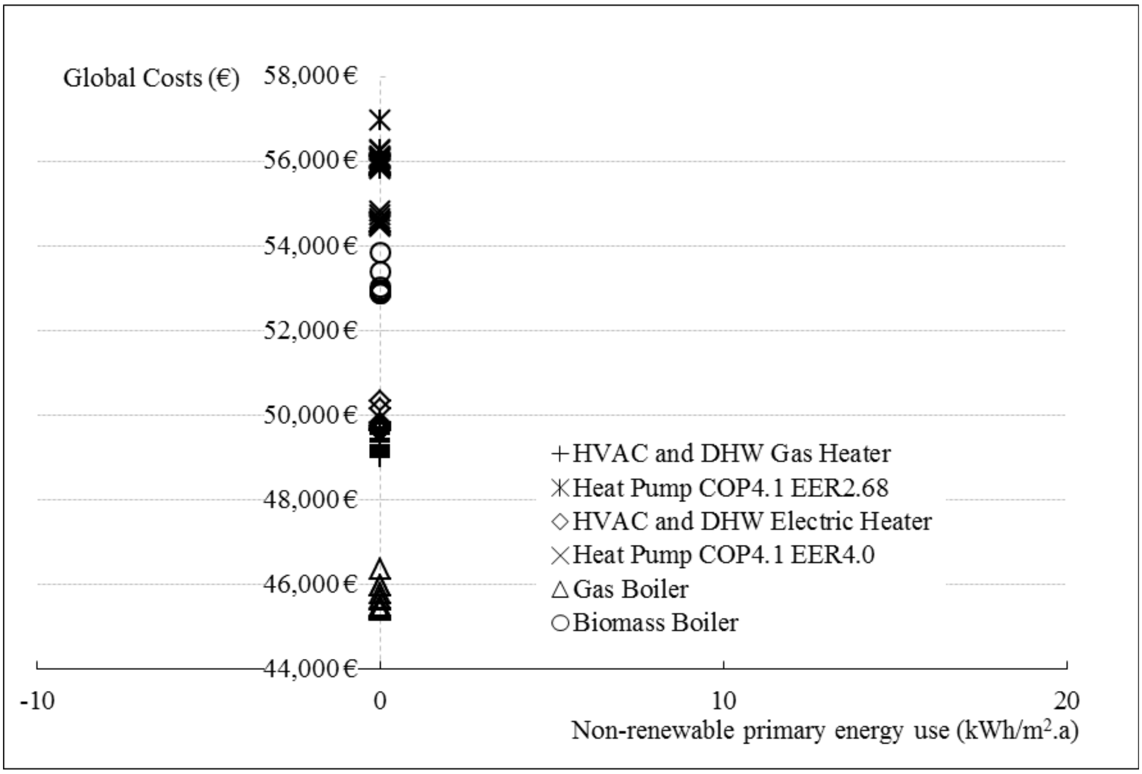

Figure 3 – Cost optimality evaluation towards zero non-renewable primary energy use

3.5. Impact of renewables on the cost effectiveness of envelope elements

The impact of on-site RES on the cost effectiveness of measures on the building envelope has also been tested.

Figure 4 presents all packages of measures to improve the building envelope in which the gas boiler has been used for heating and DHW preparation. Each mark represents a building renovation variant (VAR) with its non-renewable primary energy use and global costs.

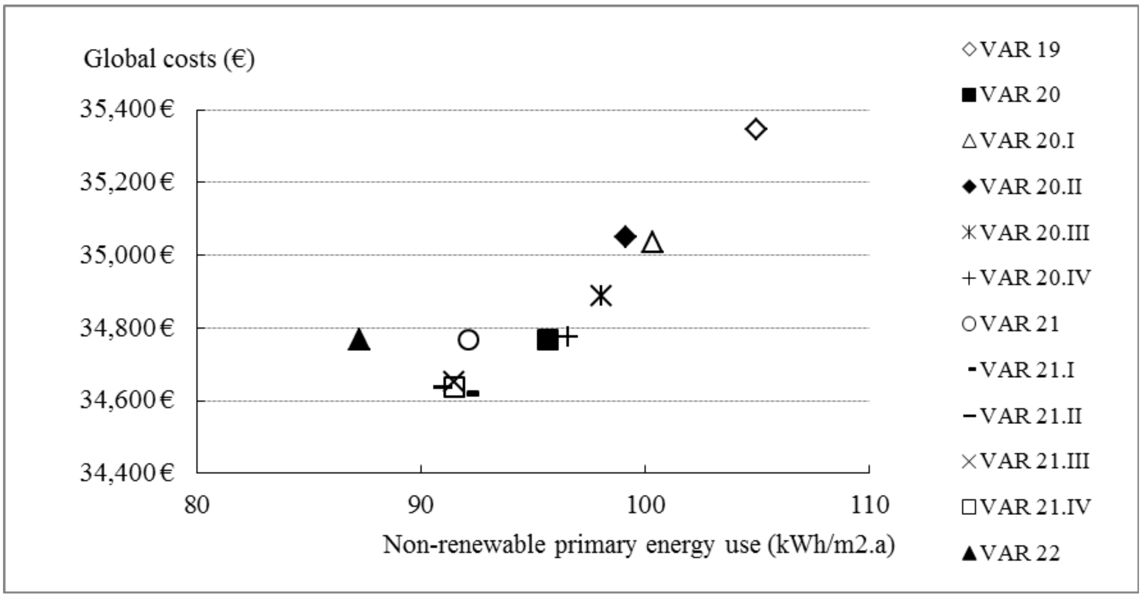

Figure 4 – Cost optimality evaluation with the use of gas boiler for heating and DHW preparation

The cost optimal package of measures, identified as VAR 21.I, includes ETICS in the outer walls with a 100mm thick layer of EPS; a 140mm thick layer of PIR on the ceiling; a 50 mm thick layer of PIR in the basement ceiling; and PVC frames with double glazing in windows.

After the introduction of thermal solar and photovoltaic panels to obtain a zero non-renewable primary energy balance, the package of measures leading to the optimal cost is a slightly more efficient one, as can be seen in Figure 5. In this case, the package of measures with the lowest global cost is identified in Figure 5 as VAR 21.IV - ER and includes ETICS in the outer walls with a 120mm thick layer of EPS; a140mm thick layer of PIR on the ceiling slab; a 50mm thick layer of PIR in the basement ceiling; and PVC frames with double glazing in windows.

The package of measures with the lowest global cost, when the goal is zero non-renewable primary energy balance, presents a level of insulation in the exterior facade slightly above the value of the renovation package that led to the optimal cost without the zero energy target. This package, due to the high investment costs in on-site RES, has an associated global cost of approximately €10,800 higher than the cost optimal package without renewables, which means an increase of nearly 30% of the global costs and an increase of nearly 50% in the investment costs.

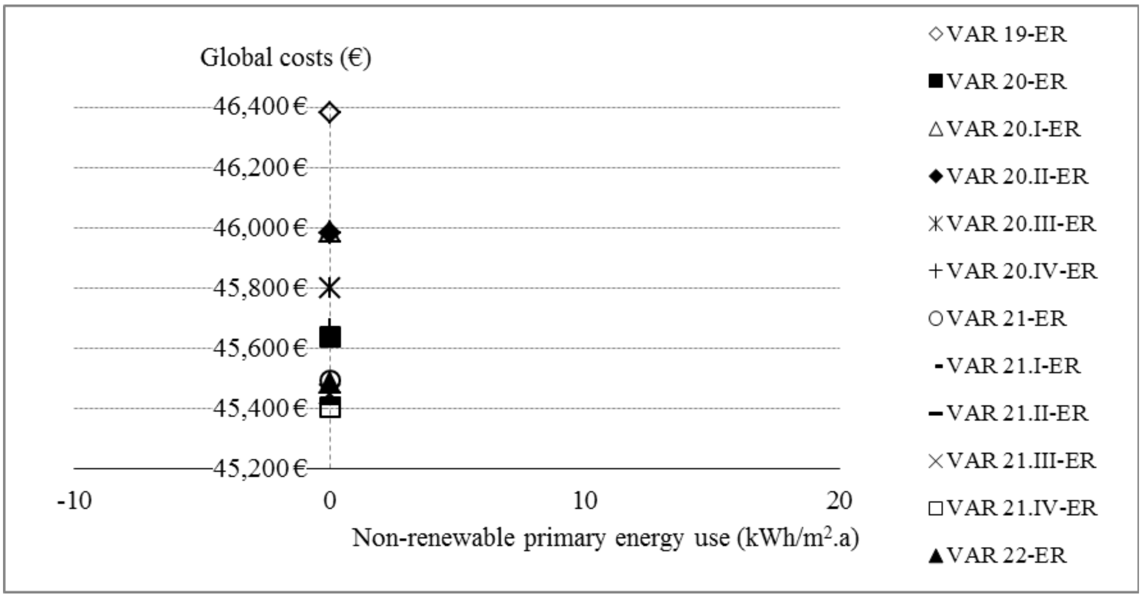

Figure 5 – Cost optimality evaluation with zero non-renewable primary energy use with the use of gas boiler for heating and DHW preparation

Analyzing the other systems for HVAC and DHW, the variations are very similar to the ones presented for the gas boiler. In the case of the multi-split HVAC with the electric heater for DHW and also in the case of the biomass boiler for heating and DHW, a change in the package of measures with the lowest global cost occurs for a package of measures with a slightly better energy performance. In the case of the heat pumps and also in the case of the multi-split HVAC with a gas heater for DHW, the cost optimal package is also the package with the lowest global cost in the evaluation for zero non-renewable primary energy use.

Considering these results it is possible to conclude that the installation of on-site RES doesn´t change significantly the hierarchy of cost effectiveness between the different packages of measures in the building envelope. Nevertheless, there is a clear tendency for the reduction of the gap in global costs between the cost optimal package of measures and those with better energy performance and in some cases the lowest global costs are obtained with packages with slightly better energy performance.

4 CONCLUSIONS

The results presented in this article are part of a broader ongoing work that will consider single-family buildings from different periods and in different locations in Portugal. Although actual results are only referring to a single building type and location, they already allow drawing some conclusions concerning the cost effectiveness of the combination of measures to improve the energy performance of the building envelope and of the HVAC and DHW systems and the use of on-site harvested renewable energy to achieve a zero energy balance.

Without the restriction of zero energy balance, the cost optimality is found for packages of measures using natural gas, if only for DHW or also for heating. If natural gas grid is not available, the packages of measures using a multi-split HVAC system combined with electric heater for DHW, the biomass boiler or the heat pump, all present very similar global costs with significant differences in the non-renewable primary energy use. In these cases of similar global costs, the building variants with the lowest non-renewable primary energy should be chosen.

With the introduction of a solar thermal system to reduce the DHW energy needs and photovoltaic panels to generate electricity in a quantity that equals the non-renewable primary energy use, the hierarchy of cost effectiveness from the several used HVAC and DHW systems, didn't suffer major modifications. An exception has been observed in the synergy with the packages of measures using an electric heater for DHW, certainly due to the significant reduction of the energy needed to increase the water temperature by the effect of the solar thermal system, reducing the impact of the use of a low efficient system such as the electric DHW heater.

Considering the impact of the use of on-site RES on the cost effectiveness of the measures in the building envelope, it is possible to conclude that although their use doesn´t change significantly the hierarchy of cost effectiveness between the different packages of measures, there is a tendency for the reduction of the gap in global costs between the cost optimal package of measures and those with better energy performance. In some cases the lowest global costs are obtained with packages with slightly better energy performance than the cost optimal package without a zero energy restriction.

The actual results, which are to be confirmed with studies on other buildings from different periods and located in other parts of the country, point out to a robustness of the cost optimal methodology in the definition of the most cost effective packages of measures in the building envelope, with very similar results for a zero non-renewable primary energy goal or without this restriction. Nevertheless, a cost optimal range instead of a cost optimal single package should be considered, once some combinations of HVAC and DHW systems and on-site RES, shift the cost optimal envelope package to a different one with slightly better energy performance.

Complementary, these results also point out to synergies between the use of on-site RES and the DHW systems, allowing the choice of simpler equipments with a lower investment cost and reducing the impact of the use of electricity as the energy vector in the quantification of the non-renewable primary energy.

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Zero-Energy-Urban-Quarters in different climates: Derivation and application of design strategies based on climatic parameters.

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ABSTRACT: In a Zero-Energy Building, the primary energy demand for heating, cooling, ventilation, hot water and artificial light should be reduced to zero. To reach this goal, buildings have to be optimised energetically. Nevertheless, some energy demand will always remain and has to be covered by renewable energy sources gained on site (photovoltaic, geothermal etc.). The resulting competition between the area of use (producing energy demand) and the area of the roof / the building envelope and the size of the building estate leads to limitations in the urban design. First of all, the maximum number of storeys for the single building and secondly – to avoid shading – the minimum distances to neighbouring buildings have been investigated here. In a student course, optimised standard office rooms for 15 different locations with 15 different climatic conditions have been developed. Their energy demand has been simulated and compared with climatic parameters such as heating and cooling degree hours and a good correlation between them could be proven. The resulting linear correlation equations may serve as a tool for the assessment of the energy demand of energetically optimized buildings, based only on climatic parameters – which can be especially important before the first design step. The application of this tool to Porto and Hamburg leads to different proposals for optimised buildings and their arrangement in an urban situation. While in Hamburg a satisfying urban density can be reached only with compensation measures for heating and power, the situation in Porto allows for buildings with up to 7 storeys and a high urban density.

1 INTRODUCTION

In the European Union, the building sector is responsible for 40% of the primary energy demand. Thus, a notable reduction could be achieved by energetically optimising the building stock, especially in the context of zero-energy standard being pursued. According to the Energy Performance of Buildings Directive (EPBD) 2010/31/EU, new and retrofitted nearly-Zero-Energy-Buildings should be reached by 2020, setting minimum requirements for both the envelope and the technical systems (EPBD, 2010). In a Zero-Energy-Building (ZEB) 100% of the consumed primary energy has to come from renewable energy sources. As claimed by the directive, these renewable energy sources have to be gained on site, e.g. on the building's façades / roof and/or in the estate's ground. Weaker ZEB definitions allow compensation measures to balance energies: transfer of renewable energy sources produced off site or co-generation etc.

Up to now, two different concepts of energetically optimised buildings exist. A passive method where the building's energy demand is minimised by passive measures ("Passive House") and an active approach where solar panels and similar technical measures are used to cover the energy demand ("Solar House"). The application of only one of these principles is not sufficient to reach a ZEB.

A well-designed synthesis of both is necessary, following the sequence: reducing the building's primary energy demand to its minimum with design strategies, covering the remaining primary energy demand with renewable energy gained on site and use compensation measures to bring the balance to zero. For some locations in the world, it is possible to cover the primary energy demand on site, for others not. The first two points create a further competition between the façade's transparent areas (for optimal daylight supply and minimal power demand for artificial light) and opaque areas (for solar panels to gain renewable energy). Furthermore, the whole building shape will become an important passive measure to optimise energy demand and production. The architect is in charge of an optimised building shape, which can be applied at an early design stage.

As solar radiation should have access to façades and roof surface, distance and placement of buildings in an urban situation represent a core aspect. Therefore, an integrated energy concept starts with urban planning and not just on the building level.

Different locations have diverse needs and preconditions, leading to different design rules and architectural solutions for zero-energy urban quarters and buildings in different climates. Such a design approach is climate responsive and should lead to a new culture of climate-responsive architecture.

2 METHODOLOGY

The M.Sc. Degree Programme "Resource Efficiency in Architecture and Planning" (REAP, 2012) at the HafenCity University Hamburg emphasises holistic design for sustainable urban development projects, including scientific approaches of water, material and energy concepts. In this context, the course "Climate-responsive Architecture and Urban Planning" encourages the students to apply their knowledge of building physics to buildings around the world. With the task of adapting buildings to the conditions of local climate and optimising indoor comfort, students are required to investigate their own case study. Passive and active measures should be applied as far as possible. The overall aim of the course is to find out if and how far it is possible to realise ZEBs in all parts of the world; a detailed description of the course can be found in (Dietrich, Kiehl, Stoica, 2013).

For the course, 15 different locations in different latitudes were preselected: Reykjavik, Oslo, Hamburg, Chicago, Beijing, Cairo, Delhi, Mexico City, Santo Domingo, Addis Ababa, Singapore, Dar Es Salaam, Jakarta, Sydney, Santiago de Chile. For this paper the location Porto was supplementary regarded on the basis of the prognosis tool described in chapter 6.

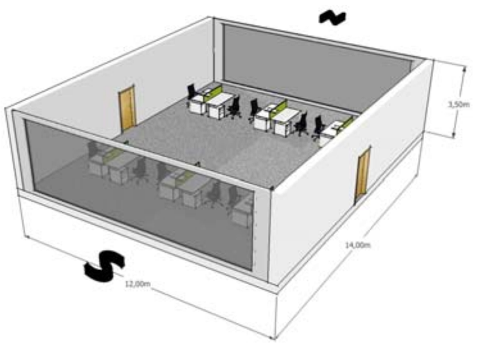

Figure 1. International style office room.

To simplify the task and to be comparable between all student groups / locations, it was predetermined to deal with a standard office room for 12 users (area of usage 168 m²). It was assumed that this room could be one of a series of rooms, situated in the middle of an office building so that the building continues horizontally and vertically.

As a starting point "before optimisation", an "international style" standard room was defined. This room has two fully glazed façades, an internal shading system, light construction, air conditioning (26°C) and artificial light and is operating during the whole time of use (7am to 6 pm). The room has been simulated with a self-developed interface on energy plus (Primero-Comfort, Primero 2013) in advance for all the locations, data of the energy demand for heating, cooling, artificial light and ventilation was given to the students.

Based on these data, each student group had to estimate the maximum number of storeys and the minimum distance of neighbouring buildings to reach a ZEB with international style rooms in one of the given locations. Therefore they had to deal with the façade / roof areas as collector surface and/or the estate area for geothermal systems in their first presentation.

The second presentation included an analysis of vernacular and best practice architecture in the given locations as well as the location's climate and the derivation of design strategies.

Based on this knowledge, students should optimise the international standard office room according to the local conditions. The subjects covered in the final presentation included the estimation of the maximum number of storeys and the minimum building distances to reach a ZEB. The rooms had to be optimised, so that collecting surfaces and/or the estate area could be used to cover the energy demand with renewable energy sources. First rules for regulations in climate-responsive urban planning were derived from this.

In order to develop the final design and urban situation of the climate-adaptive building, it was necessary to have information about the energy demand of this optimised room as a starting point. One possibility for them was to simulate the proposed optimised room during the course. Although this is possible, experience shows that these simulations are often too complex and time consuming, distracting students from the main target of the course. For this reason, another method has been developed to avoid these simulations. The results of the first cycle of our course were a row of optimised rooms for different locations. These rooms have been simulated and a comparison of the resulting energy demand with other typical data for the same location, like heating or cooling degree hours, and found a very good correlation between them.

Based on these correlations, the student groups have been offered an estimated energy demand for optimised rooms in their location. The results are accurate enough for the main target of the course and help to avoid the execution of further detailed simulations.

The energy concept that should be applied in all case studies is based on a combination of geothermal heating and cooling and solar energy (PV modules) for the generation of electricity.

The geothermal system consists of borehole heat exchangers in the ground, coupled with an electrically driven heat pump. The boreholes are assumed to have a depth of 100 meters, using the ground as a heat source in winter and as a heat sink in summer. Each borehole needs to be placed a specific distance away from the next one. For this distance, 10 % of their length has been suggested, leading to the rule of thumb: one meter of borehole needs 1 m² of estate. One meter of a borehole is able to deliver 600 Wh of thermal energy per day (Zimmermann, 1999). The size of the geothermal system is determined by the maximum daily heating or cooling energy. For the heat pump, a coefficient of performance (COP) of 2.5 was assumed for cooling and 3.5 for heating. Geothermal systems are being used more and more around the world, especially in combination with optimised buildings. Thus, they seem to have a big future.

The power demand of the heat pump, artificial light and mechanical ventilation has to be covered by PV modules, which can be installed on either the building's roof or façades. In case PV modules are installed on pitched roofs or façades, buildings need a minimum distance to avoid one building from shading the next. For power, a primary energy factor of 3 has been used for all calculations.

If it is not possible to meet the target, using only on-site renewable energy in an urban scenario, compensation measures have to be proposed.

3 ADAPTIVE, HYBRID OR AIR-CONDITIONED?

An adaptive building is understood as a building where the users can adapt their surrounding according to their preferences: Operable windows, personal switches for artificial light, mechanical ventilation, thermostats etc. If users are allowed to adapt themselves to (higher) indoor temperatures during hot periods by changing their clothes (no or weakened dress code!), investigations show that users may feel well in remarkably higher temperatures than in non-adaptive surroundings (air-conditioned buildings).

Adaptive comfort models such as (EN 15251 2007) differ between naturally ventilated (adaptive) and air-conditioned (non-adaptive) buildings. For both building classes EN 15251 distinguishes three comfort classes: 1- high standard (for special uses like hospitals), 2 - good standard (for all new buildings), 3 - low standard (acceptable for refurbished buildings). The relevant comfort belt may be exceeded during a limited part (3 or 5%) of the hours of use. For an office, this means that about 100 hours per year are allowed to exceed the comfort belt.

In air-conditioned buildings, the user expects a constant temperature (mostly 26°C) independent of the outdoor situation. In adaptive buildings, the expected temperature varies slightly with the mean value of outdoor temperature.

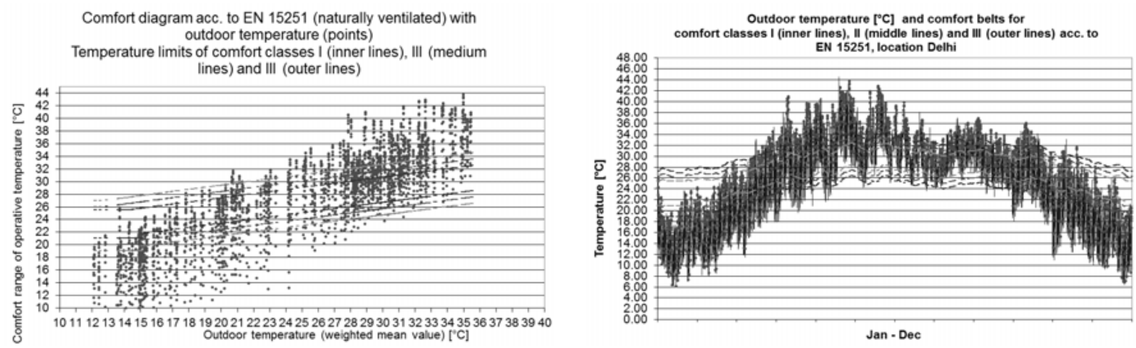

Figure 2. Comfort diagram according to the scheme of EN 15251 (left) and with comfort belts according to EN 15251 (right), assessment of outdoor temperature in Delhi.

Figure 2 illustrates this situation. Left, the comfort belts for the three comfort classes are marked. The indoor temperatures are normally displayed as points in this EN 15251 scheme to assess indoor climate. In this diagram however, the points represent outdoor temperatures.

Given the fact that for real air changes, indoor temperatures remain a few degrees below outdoor temperatures for heavy construction – or are almost equal to outdoor temperatures for light construction, an adaptive comfort model such as EN 15251 provides a good tool for pre-assessing, if there is a chance for reaching comfort during hot periods with passive measures (natural ventilation). As an example, Figure 2 (left) shows a lot of points for Delhi, which are both below and above the upper comfort limit – the number of points exceeding the comfort level makes up much more than 3%. To conclude however, that comfort can't be reached in an adaptive building but only in an air-conditioned one would be premature. If the x-axis of the EN 15251 scheme is changed into the real-time axis, a different picture can be shown (Figure 2, right). Now it can be seen, that the upper line of the comfort belt is not exceeded during most of the months, so that an adaptive building is possible here. Only during the hottest months, an air conditioned building is necessary. Summing up the findings so far, a hybrid building can be suggested, operating for 5 months in an adaptive way (saving a lot of energy for the mechanical ventilation and cooling system) and 7 months with air conditioning.

Comfort class 2 can be reached with adaptive building concepts during the whole year in Reykjavik, Oslo, Hamburg, Mexico-City, Addis Ababa and Sydney. If users in hot climates are adapted to it and would accept higher temperatures than assumed in EN 15251, the upper line of the comfort belt can be shifted upwards. Then, comfort class 2 can be reached in Singapore, Santiago de Chile (1 degree), Beijing, Santo Domingo, Dar es Salaam (2 degrees), Cairo and Jakarta (3 degrees). If users accept this upward shift, adaptive buildings are possible. If not, hybrid or air-conditioned solutions have to be developed. Comfort class 2 can never be reached in Delhi, meaning a fully adaptive building is not possible, a hybrid one like described would be the best option.

4 CASE STUDY RESULTS

4.1 *International style standard office room*

Figure 3 (left) shows the primary energy demand for the "international style" office room in all 15 locations. Where high solar transmission occurs through the façades, cooling demand is a dominant factor. The highest demand occurs in the hottest locations (Delhi, Cairo, and Jakarta). Even in locations with moderate temperatures during summer such as Oslo and Hamburg, a cooling demand exists. In general, the level of primary energy demand is very high - a clear sign of the potential to optimise "international style" office buildings.

In order to cover the power demand for heat pump, artificial light and mechanical ventilation with PV modules (installed on the building's envelope) a limited number of storeys is possible only; in the worst case (less than) one (Oslo, Reykjavik) up to 3 storeys (Mexico-City, Addis Ababa). Due to high demand of thermal energy for heating and especially for cooling a large estate is required to implement the geothermal system. To supply a five-storey building, the required distances between buildings reach from 30 m (Mexico-City, Addis Ababa, Santiago de Chile) to more than 100 m (Delhi, Oslo).

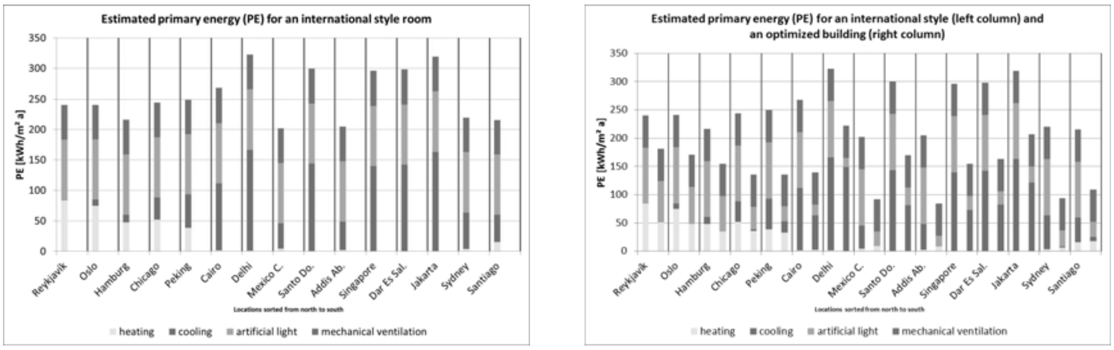

Figure 3. Primary energy demand of standard office room for 15 locations, left "international style" and right "international style and optimized.

Generally, the attempt to develop a zero-energy urban situation using "international style" buildings delivers unsatisfying results. The energy demand is too high. The necessity to reduce this demand further becomes aware in order to reach a satisfying situation.

4.2 *Optimised standard office room*

Before starting the optimisation of the room it has been necessary to decide whether the users are allowed to behave adaptive or not (e.g. dress code, company philosophy, number of users per operable window/thermostat etc.). If so, an adaptive building can be proposed and designed. If it is necessary to switch during very hot periods to an air-conditioned building, a hybrid building can be designed. If even that is not possible, an air-conditioned building has to be designed. The cases examined in the following deal with air-conditioned buildings. This is not meant to reduce the relevance of adaptive building solutions but should demonstrate the potential for energetically optimisations. Adaptive solutions will reduce the energy demand remarkably further! Figure 3 (right) shows the primary energy demand of an (air-conditioned) optimised room in comparison to the "international style" office room. The reduction potential is remarkable for all locations but differs for each one. For locations with cold winters, the optimised room has opaque façades with high thermal insulation, leading to a small reduction of heating demand. The reduction in power demand for artificial light has the biggest impact in locations with a clear sky, receiving 12 hours of daylight during the whole year (e.g. near the equator, see Cairo, Delhi, Addis Ababa). It is assumed, that no artificial light is used, if enough daylight is available.

Cooling demand can arise from high solar transmission through façades and/or a high outdoor temperature. To counteract solar transmission, buildings can be optimised with adequately sized window areas and efficient shading systems. Important is however, that counteracting against very high (or even very low) temperatures with thermal insulation reduces their impact but not so perfect like a shading system for solar radiation. Thus, the highest heating demand occurs in locations with the lowest temperatures and the smallest opportunity of solar gains during winter (Reykjavik, Oslo). The highest cooling demand occurs in locations with the highest temperatures (Delhi, Jakarta) – here the potential for optimisation is limited. The highest reduction in energy demand is found in locations where cooling demand for an "international style" room arises from solar transmission (Santo Domingo, Singapore, Dar es Salaam, Sydney).

When trying to cover the power demand with PV modules, installed on the building's envelope, it becomes clear once again, that only a limited number of storeys is possible. In the worst case again only (less than) one storey (Oslo, Reykjavik), 4 storeys and more (Cairo, Singapore, Sydney, Santiago de Chile, Dar Es Salaam) and up to 9 storeys (Mexico-City, Addis Ababa). Thus, with the reduced primary energy demand for the optimised office room, typical urban dimensions can be reached for some locations!

The optimisation of heating and cooling demand leads to a remarkable reduction of the geothermal system and thus the required estate size. The supply of a five-storey building with thermal energy results in acceptable urban distances between buildings (street width of about 15 m, Mexico-City, El Salvador, Sydney, Santiago de Chile, Addis Ababa) or not far from it (Santo Domingo, Singapore, Cape Town) but reach up again to 100 m in the most extreme case (Delhi).

In general, the attempt to develop a zero-energy urban situation with optimised buildings leads to very satisfying results in some locations. For other locations, a major part of the primary energy can be covered on site. Only in extreme locations, it remains very difficult to reach the target. In this case, compensation measures are necessary.

The size of the geothermal system is determined by the peak values of heating and cooling demand per day, i.e. the strength of heat and cold waves but not the annual demand. The biggest geothermal system is required in Delhi (hot and dry) for cooling and in Chicago (!) for heating. In locations with high but not extreme temperatures (the hot and humid ones: Santo Domingo, San Salvador, Singapore, Jakarta) have a high annual cooling demand but they need a relatively small geothermal system to cover it. Vice versa, locations with shorter but extreme heat waves have a smaller annual cooling demand, but they need a huge system to cover it.

The global solar radiation is the main source to cover the energy demand. The best offer can be found in the hot and dry locations (Cairo, Delhi). Here, the highest supply meets the highest demand! It seems that both can be brought into balance, but only with buildings with a limited number of 3 to 5 storeys.

Locations near the poles (Reykjavik, Oslo) have a very low solar supply, especially during the heating period. They also have a high demand of artificial light (darkness during time of use). Because of the low position of the sun, the use of PV to cover the demand seems not to be adequate. Consequently, other possibilities for the supply of renewable power or compensation measures should be regarded (Fortunately, both Reykjavik and Oslo are locations where power generation is almost 100% renewable).

The best situation exists in locations with moderate temperatures (near to the sea or with a high elevation) and a high level of solar radiation (Mexico-City, Sydney, Santiago de Chile). Zero-energy buildings as well as urban arrangements are possible for many locations but not for all. This holds true for European countries where the directive has to be fulfilled.

5 CORRELATIONS BETWEEN ARCHITECTURAL AND CLIMATIC PARAMETERS (PROGNOSIS METHOD)

The architectural parameters heating and cooling demand in optimised buildings are assumed to be determined essentially by the outdoor temperature. Therefore, a correlation between them and climatic parameters such as heating and cooling degree hours is likely.

$$HDHy = \Sigma\,(20 - Te) \quad \text{if } Te < 16°C \tag{1}$$

$$CDHy = \Sigma\,(Te - 26) \quad \text{if } Te > 26°C \qquad \text{sum only over hours of use} \tag{2}$$

$$GRHy = \Sigma\,(1) \quad \text{if } Igl,hor > 200 W/m^2 \qquad \text{sum only over hours of use} \tag{3}$$

Equations (1) to (3) define the climatic parameters annual heating (HDHy in Kh/a) and cooling degree hours (CDHy in Kh/a) and the annual global radiation hours (GRHy in h/a). Te is the outdoor air temperature in °C and Igl,hor solar horizontal global radiation in W/m². For cooling and artificial light, it is assumed that both are running only during the time of use, the sums in Equations (2) and (3) consider only this period. For artificial light it is assumed that it could be switched off if the global horizontal radiation reaches 200 W/m².

The parameters HDHd [Kh/d] and CDHd [Kh/d] are the daily maximum values of heating and cooling degree hours. They are representative for the temperature peaks in the climate; a correlation with the size of the geothermal system could be expected.

The energy demand and the size of the geothermal system have been simulated for the optimised (but air-conditioned!) office room. Between these architectural parameters and the five climatic parameters, a good correlation has been found, using the following regression equations: Y = A * X + B.

Table 1. Variables of regression equations between architectural and climatic parameters.

Y	A	X	B
Yearly cooling energy demand [kWh/m² a]	0.0108	CDHy	-3.4542
Yearly heating energy demand [kWh/m² a]	0.0005	HDHy	-3.9752
Maximum daily cooling energy demand [Wh/m² d]	7.3567	CDHd	-84.788
Maximum daily heating energy demand [Wh/m² d]	0.7691	HDHd	-62.944
Power demand artificial light [kWh/m² a]	0.0106	GRHy	-0.6389

The fit (r^2 value) of these regressions lies between 74 % and 99 %; Figure 4 shows a typical example.

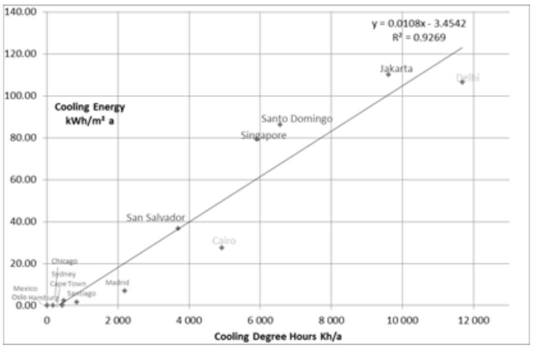

Figure 4. Correlation between yearly cooling energy demand and cooling degree hours CDHy and regression line.

Based on the equations given in Table 1, the energy demand for an optimised (but air-conditioned) building for any location in the world can be forecasted, based on only its climatic parameters. The equations provide a simple method to predict, how far energy demand can be reduced when optimising the building according to local climates.

The proposed correlations make up a good approach, even though the database is weak, including only 15 locations, and requires expansion. Additionally, the rooms have been only theoretically optimised in student projects, meaning there is no practical evidence. Further detailed investigations should lead to a more accurate prognosis method. On the other hand, the correlations are surprisingly good and plausible and the results are in accordance with real ZEBs or zero-energy urban solutions.

6 APPLICATION OF THE PROGNOSIS TOOL TO PORTO AND HAMBURG

The presented prognosis tool can be helpful for architects who can’t conduct detailed simulations in early design stages. It was used here to estimate the energy demand of an optimised but air conditioned building for Hamburg and Porto. In Porto it seems to be possible to reach comfort even without air conditioning, because of the very moderate temperatures (situation at the Atlantic) in summer (nearly always below 30 °C) and even in winter. Therefore the building can be run in an adaptive way for 12 month a year with heating only. For Hamburg, a heating system with mechanical ventilation and heat recovery is recommended for 6 month, while 6 month can be run adaptive. As a clear sky is dominant in Porto, the resulting demand for artificial light is about half of the lighting demand in Hamburg with a cloudy sky. To reach both, a good daylight supply while avoiding too much solar energy transfer into the building, a percentage of window area in the façade of 35% (Porto) and 50% (Hamburg) is recommended.

To cover the remaining energy demand for heating and power (artificial light and mechanical ventilation), the required size of the geothermal system and PV modules has been determined.

Figure 5 shows, how a typology of a ZEB and their arrangement in an urban situation could look like in both locations. Balancing demand and supply the maximum number of storeys and building distances have been derived. The calculation includes an increasing demand of artificial light for decreasing building distances.

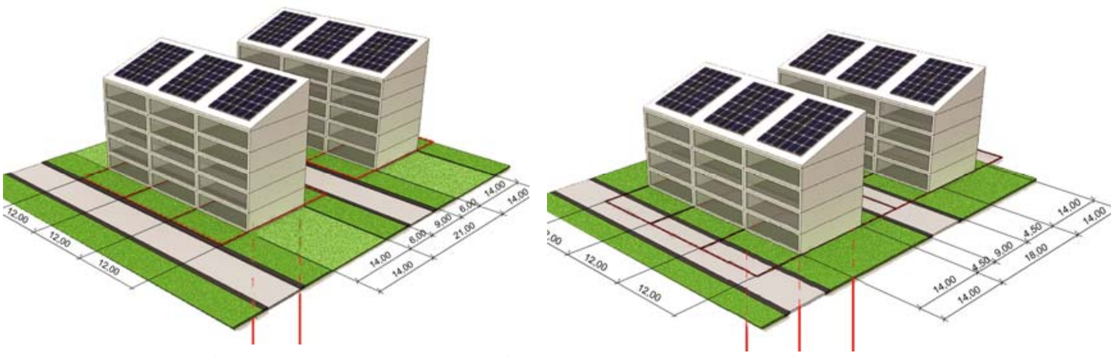

Figure 5. Example for an urban arrangement of ZEBs, locations Porto (left) and Hamburg (right)

For Hamburg the result is not completely satisfying. Defining an urban situation with at least 4 storeys and a building distance which is equal to the building height (18 m with elevated roof), a plot ratio (area of usage divided by area of estate) of 1.8 results. Only 85% of the heating demand for this scenario can be covered with the geothermal system. As PV modules on the roofs can only cover one third of the demand and solar radiation in Hamburg makes up only 60% of the solar radiation in Porto (while the demand is much higher), compensation measures for heating and especially for power are necessary.

For Porto the result is completely satisfying. A zero-energy urban quarter would be possible, even with 7 storeys and a building distance of 12 m and thus a plot ratio of 3.8. But an urban situation with small street width and high buildings would darken most of the areas of use, leading to an uncomfortable situation. Thus, the access of daylight should be the dominant criterion leading finally to another arrangement with 5 storeys, a building distance which is equal to the building height (21 m) and a plot ratio of 2. Here, the power generation by PV on the roofs exceeds the demand by a factor of five, leading to a surplus which can be delivered to the grid.

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The first phase of a Zero Emission Concept for an Office Building in Norway

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ABSTRACT: This paper presents methods and results from the first phase of a greenhouse gas emission analysis for a zero emission building(ZEB) office concept in Norway. The methodology is a stepwise approach where the goal is a zero emission building concept for office buildings. The case is based on a 4 story office concept in a Nordic climate. The final aim is to balance operational and embodied emissions by compensating the green house gas emissions with on-site electricity production from solar cells over the life time of the building.Findings indicate that emissions from construction materials and technical equipment are higher than emissions from operation phase. Materials with large volumes and high embodied emissions such as concrete, steel and the use of solar cells are main contributors. The first phase of the calculations concludes that the ambition level aimed at, to weigh up for both operational and embodied emissions, is not achieved with the current approach. Further work focusing on the use of alternative solutions and construction materials is needed in the next steps towards achieving final goals.

1 INTRODUCTION

The work presented has been conducted at the research center for Zero Emission Buildings (ZEB) in Norway. The main objective of the ZEB Centre is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases (GHG) related to their production,operation and demolition. The traditional "net"-ZEB definition has evolved mostly around the topic of zeroing out energy use in the operational phase of a building (Sartori et. al., 2012). In Marzalet. al., (2011) a review is given of definitions and calculation methodologies for Zero Energy Buildings. The review reveals that there are still many different approaches being used and there has been limited inclusion of the aspects of embodied energy/emissions. In Dokka et. al., (2013) different ambition levels for a zero emission buildings are defined. The level of ambition the office concept study aims to achieve is ZEB-OM which means a building that weighs up for emissions related to all operational energy use (O) plus embodied emission from materials and installations (M) (Dokka, et al. 2013).

The work described in this paper, started out with a simplified model and has evolved into a stepwise approach using a four storey case office building created as a Building Information Model (BIM)using Revit, version 2011 (Autodesk, 2011).In the first step the BIM is used for visual understanding and material take outs. A stepwise approach was chosen that divided this 'zero emission balance' into two phases. The first phase focuses on documenting a base case using BIM, standard office layout, traditional materials and state-of-the-art technical installations, shown in Figure 1, Step 1.

BIM known as "Building Information Modeling" or "Building Information Model" can be described as a virtual model digitalized expression for a building's physical and functional features. The information input can furthermore be utilized in structure design, equipment management and provides a solid foundation for all decisions of a building life cycle (Yuan, et.al. 2011). In addition the BIM-model could be utilized to generate input data files for energy simulations programs.

A study using plug-ins such as Green Building Studio (GBS) or Integrated Environmental Solutions' Virtual Environment (IESVE) hypothesised that; although plug-ins provide quick results that are useful to building designers, a full-process Life CyleAsessment (LCA) using SimaPro and BIM would promote a better understanding of LCA methods and a better basis for a more complete analysis (Stadel, et.al. 2011).One study using BIM argues that a significant portion of a building's life-cycle impacts is determined by decisions made in the early design stages and choices of material at this stage makes a great difference in reducing a building's life cycle impact (Basbagill, et.al. 2013).

2 THE BUILDING

The case office building concept has a total of 1980 m^2 heated floor area and the office area consists of a mix of office cells and open landscape. The area also contains meeting rooms and common spaces. The cellar, used for technical rooms and parking, is unheated and not included in the heated floor area, although included in the material emission analysis. The general design of the building does not impose restrictions on the floor plan in having the possibility of frequent changes over time (Arge, K., 2003). The structure and fittings are designed with regard to a high level of flexibility. Dismantling, removal and installations of partitions are easy to manage without extensive demolition and construction work and without having to make large electrical and/or mechanical reconstructions. The office areas are suitable both for open floor plans and/or office cells, or a combination thereof. The model presented here is composed with objects containing designated information used in the calculations.

The building physics and energy concept for the office building model are described in the Technical report on the Office concept by Dokka et. al. (2013). However, a short review of the concept is presented here. The Norwegian passive house standard NS3701:2010 has been used to develop an energy efficient building envelope (Standard Norway, 2010). The total windows and doors area is 456 m^2, which gives a windows/doors to floor area ratio of 23 %. The building has a high performance building envelope achieved by using materials and solutions already available on the market. The U-values and levels of insulation of the envelope are given in Table 1. Furthermore, the building envelope has an air tightness of < 0.3 arc@50 Pa, and the air flow rate is 7,0$m^3/h \cdot m^2$ during hours of operation and 0.7 outside.

Table 1. U-values of different parts of the envelope

Construction part	U-value [W/m²K]	Insulation thickness [mm]
Timber framed outer wall	0,12	350
Roof	0,09	450
Floor against cellar	0,11	350
Windows	0,75	-

The energy supply system is based on a heat pump, solar thermal panels and solar electric panels. Simulations of the annual energy performance of the building have been carried out using SIMIEN version 5.011 (SIMIEN, 2012). The performance of solar collector system and the heat pump system have been done by simulation in PolySun (Polysun, 2012) and performance of the PV-systems have been simulated with the solar energy simulation program PV-syst (PV-syst, 2012).

3 METHODOLOGY

The overall methodology is shown in Figure 1. This paper is concentrated around step 1 of the embodied emission calculations, shown on the right side of figure. TEK10 refers to the Norwegian regulation ontechnicalrequirements for construction (KRD, 2010). The approach regarding the energy concept is described in Dokka et. al.,(2013).

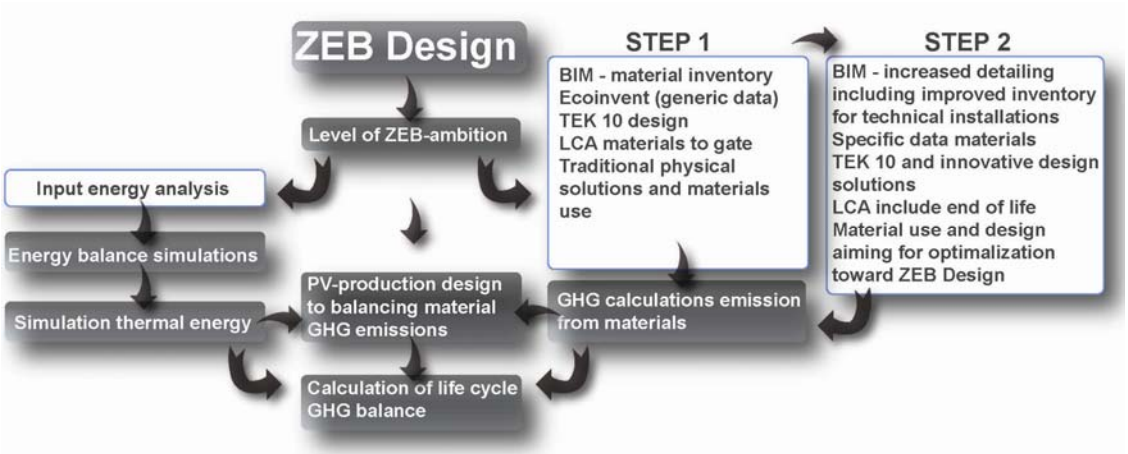

Figure 1 A step wise methodology on calculation towards a ZEB.

The following subsections describe the embodied emission calculations performed in step 1.

3.1 *Scope, aims and ambition level*

The goal of these calculations is to estimate the embodied emissions in the materials and components and emissions from the operational energy, and then calculate the GHG emission balance with the offset on site renewable energy production.

3.2 *Life cycle emissions*

In 2011 a new standard was launched; EN15978:2011 that gives the calculation framework for conducting a life cycle assessment of an entire building (Standards Norway, 2011). This study seeks to follow the basic framework of this standard. The focus has been on the GHG emission and not a full environmental assessment. The SimaPro version 7.3 has been used for the emission analysis (SimaPro, 2012) where the Global Warming Potential with a 100 year scenario is used. This method is developed by the Intergovernmental panel on climate change (IPCC, 2007).

3.3 *Functional unit*

The functional unit used in the analysis is 1 m^2 of heated floor area in the office building over an estimated life time of 60 years.

3.4 *Boundaries*

The analysis focuses on module A1-A3 from EN15978 which is material inputs to gate and the use phase replacements B4. The emissions from energy use in operation are connected to the use phase B1 (Standard Norway, 2011). The expected service lifetime used for the different materials and components is mainly based on product category rules for different materials and components. The product category rules for different building materials and construction parts are available from the Norwegian EPD foundation (EPD-Norway, 2012). The life time of the solar cells is set to 30 years with reference to recommendation from (IEA, 2011). The end of life phase is not included at this stage.

3.5 *Inventory*

The follow section describe the methodology applied in the inventory phase, the complete inventory for the analysis is available in the Technical report by Dokka,et. al.,(2013).

3.5.1 *BIM and embodied emissions*

The study on the embodied emissions is based on quantities derived on the material take off from the Building Information Model. The detailed dimensions of the material inputs has simplified the life cycle inventory phase and improved the level of detail of the material inputs. Both the lists from the BIM (Excel sheets) and the modeling in SimaPro have used the structure of the table of building elements from NS 3451:2009 (Standards Norway, 2009) which has simplified traceability and flexibility of the calculations.

3.5.2 *Encountered challengesusing BIM in LCA*

The level of details in the model, reflect the levels of details extracted in terms of material inputs. Different types of BIM tools allow for different levels of details when drawing the constructions. In the example of the slab structures the concrete amounts from BIM are based on a full concrete slab, but in reality the building is dimensioned to use hollow core elements. At this stage hollow core elements have not been drawn into the model, and a reduction of 20 % of the total volume compared to compact concrete has been estimated. Another example is the use of steel in inner walls, where there usually are used steel studs in the inner wall concepts based on gypsum. The amounts of steel used in inner walls are based on estimates from handbooks from producers and on the SINTEF Building Research Design Guides(SINTEF, 2012).By applying more refined modeling the detailing of the model can increase and finally become as detailed as the building is as built.

3.5.3 *Environmental data*

Wiberg, et. al. (2011) emphasizes the need for a transparent robust calculation method for GHG emission calculations from materials in Zero emission buildings. The current status in Norway is that there is a continuously increasing availability of environmental product declarations (EPDs) for building materials and components. Furthermore Statsbygg**,** the Norwegian government's key advisor in construction and a partner in ZEB has developed version 4 of a GHG accounting tool called Klimagassregnskap(Selvig, 2012). The tool can assist in early decision making enabling the developmentof more climate friendly buildings. However, seen in a research perspectiveKlimagassregnskap is not considered appropriatein this study, due to limited transparency and control of the input data. Neither is the use of environmental product declarationssince the methodologies used arenon consistent and transparency is still limited. The standard EN15804:2012 (Standards Norway, 2012) gives guidelines on for how to perform a life cycle assessment of building products and current work in the Norwegian EPD foundation is expected to make the EPDs more transparent and robust for comparison. Due to the lack of information and current inconsistency, it was decided to use data from the Ecoinvent v. 2.2 database, (Ecoinvent, 2010) in the first step of the concept calculations. The Ecoinvent is a Swiss based European life cycle inventory database. The methodology used in the inventories is presented in Frischknecht et al., (2007).

The calculations presented here are not based on a single emission factor for electricity. Processes from theEcoinvent database are applied with no adjustments regarding source of electricityused. Mono crystalline solar panels with an efficiency of 15,4 % are used as the data for the solar panels. It is estimated that solar cells will be 50 % more effectively produced in 30 years, when it is time for them to be replaced. This decision is influenced by Alsema, 2006. However this kind of adjustment is not in accordance to the standard EN15978 where future scenarios are not included. The material inputs of the technical units are based on experiences from ZEB pilot buildings (Kristjansdottir et al., 2012).

3.6 *Simplification and uncertainty*

Calculations for GHG emissions for technical units, such as the ventilation system components are based on estimations of raw materials. In the next step of this research these estimates have to be further studied and refined, especially on gathering environmental data for the different components used. The service lifetime for solar cells is also uncertain but the consensus, on using 30 years as the service life from the methodological guidelines for LCA of photovoltaic electricity generation is assumed to be the best available approach (IEA, 2011). The service life time of the different materials and components used is also an uncertainty factor and needs further attention.Building material losses on site are not included in this analysis. Neither are chemical substances such as glue and paint for surface treatment.

4 RESULTS

4.1 *Emissions from operation*

In the case of a ZEB-OM, the renewable energy produced at site needs to compensate for the emissions that are embodied in all the materials and due to operational energy use. Total annual net energy demand is simulated to be 57 kWh/m^2 per year, and the total annual electricity delivered to the building is 33 kWh/m^2per year; which has to be compensated by local electricity production. The emissions related to operational energy (electricity) are approximately 4.3 kg CO_2eq /m^2 (Dokka, et. al. 2013). The operational emissions are based on conversion from energy to emissions through the ZEB average factor for GHG emissions electricity production of 0.132 kg CO_2eq/kWh. The ZEB emission factor is based on best case scenario calculations for electricity production in Europe in the period 2010-2070 made by Graabak&Feilberg, (2011).

4.2 *Emissions from materials*

The results of the first step of the embodied emission analysis are summed up in Table 2. The results are mainly presented for emissions on an annual basis, where the functional unit of 1m^2 is divided by 60 years. The total embodied emissions for the office building at this stage are approximately 8.5 kg CO_2eq/m^2 annually.

Table 2. Results embodied emissions.

Phase	Amount [kg CO_2eq /m^2]	Amount [kg CO_2eq/m^2 per year]
Initial material use	384	6,4
Replacements	126	2,1
Total	510	8,5

In Figure 2 the results of the embodied emissions are presented according to the table of building elements. From the figure, it is clear that the emissions related to the power producing solar cells have the highest emissions. If the solar cells are not estimated to be produced in a 50 % more efficient way in 30 years, and the same Ecoinvent process is used the total emissions will be approximately 9,2 kg CO_2eq /m^2 per year or approximately 0,7 kg higher. The PV system alone account for between 2.1-2.8 kg CO_2eq /m^2per year depend on the replacement scenario. Results also show that concrete, steel, inner walls, and exterior walls all contribute to high GHG missions. The total emissions from concrete are around 1,9 kg CO_2eq /m^2per year (around 875 m^3 of concrete).

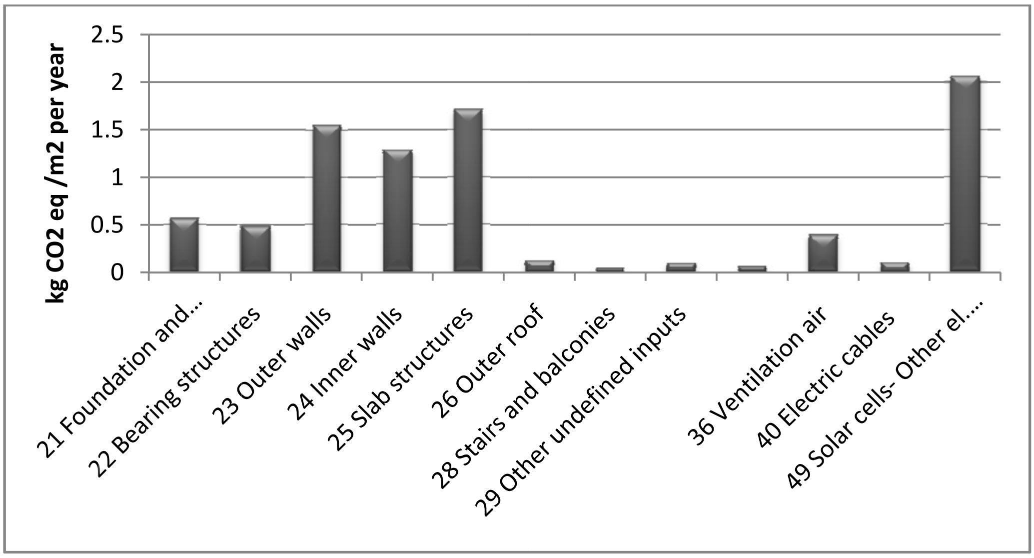

Figure 2 Life cycle embodied emissions divided by the table of buildings elements, NS 3451:2009 and based on A1-A3 and a scenario for B4 from the EN15978:2011.

4.3 *Compensating Emissions with local energy production*

Combining operational emissions and embodied emissions the total emissions that need to be offset are approximately 12.8 kg CO_2eq /m^2 annually. The energy produced using 675 m^2 of solar cells covering the roof area and south façade have been simulated to produce around 52 kWh/m^{2}of heated floor are based on an Oslo climate. This energy production can offset around 50 % of the total emissions, when applying the ZEB average factor, 0,132 kg/kWh for the GHG emissions per kWh over the lifetime. The energy needed to offset all the calculated embodied and operational emissions must amount to approximately 97 kWh /m^2 annually.

5 CONCLUSION

The results from this first step of calculations show that the emissions from embodied energy are much higher than emissions from operation. The calculations conclude that the ambition level aimed at, to weigh up for both operational and embodied emissions, is not achieved with the current approach. Further work focusing on the use of alternative solutions and construction materials is needed in the next steps towards achieving final goals. The results indicate that the embodied emissions in the solar cells themselves are high and the use of solar cells needs to be well designed in order to optimize the climate mitigation effects. The bearing systems with the slab structures and foundations also contribute largely to the embodied emissions. Many of these aspects will be looked at in the next phase of the calculations, step 2. The estimated service lifetime of different components and materials has influence on the results and needs further attention. The emission pay back calculations, here based on the ZEB emissions factor, are complex and need to be refined and analyzed further.

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Assessing design practices towards nearly Zero-Energy Buildings

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ABSTRACT: The EPBD-recast, brings EU countries new challenges on the energy performance of buildings as we move towards nearly Zero-Energy Buildings (nZEB). Architects, engineers and other stakeholders must work together in order to achieve the goals on energy performance of buildings. In the housing sector, the main stakeholders are private investors – home owners or real estate developers. However, their goals and approaches often vary along the construction process, in different stages, resulting in a modified built solution that may affect the initial goal, when it comes to energy performance. This paper analyses the design and construction processes, with case-studies of Portuguese buildings, in order to identify the critical decision-making stages that influence energy performance, and the role of each intervener. In order to assure the future on the design and construction of nZEBs, is necessary to identify the challenges that we face to meet the targets on energy performance of buildings.

1 INTRODUCTION

In Europe, buildings are responsible for around 40% of energy consumption, and 36% of CO2 emissions (BPIE, 2011a). Residential buildings represent 75% of the building stock of Europe (BPIE, 2011b), corresponding to the main practice of designers and builders all over the European Union (EU). In Portugal alone, the building sector is accountable for around 28% of energy consumption, where residential buildings represent 17% of this value (DGEG, 2011), i.e., more than half. Residential buildings constitute the most common practice, either new or subject to renovation, single family houses or apartment blocks.

With the recast of the Directive on energy performance of buildings (EPBD, 2010), which stipulates that after 2020 all new buildings built in the European Union must reach nearly zero-energy levels, including high standards on energy performance also for existing buildings, subject to major renovation, new challenges arise for the construction sector and all its stakeholders. The directive stipulates high energy performance and the use of renewable energy sources to cover the low energy needs of these buildings. In order to reach these ambitious targets it is necessary to reflect on the processes involved in construction, from design to conclusion, and the role of all the stakeholders.

Currently, it is frequent that what is predicted at the design stage is modified along the process, resulting in a different built solution, that may affect the initial goal on energy performance. These changes happen in different stages, for several reasons and by the hand of different stakeholders. This arises several questions that need to be debated in order to understand the process and the role of each intervener, and to develop long-term thinking on the design and construction processes towards nZEB.

The aim of this study is to understand what happens in all stages of the construction process that directly influences the energy performance of buildings, centering the study on residential buildings, in order to answer the questions: What motivates changes during the process? What are the main decision making stages? Who are the main stakeholders involved? How are the energy performance aspects accounted for during the whole process?

The answers to these questions will help to understand the design and construction processes and the main stakeholders that control the decision making, their motivations and the critical stages, in which changes occur. This will allow to develop methodologies to assure that the assumptions made, at the design stage, on energy performance, are accounted for throughout the whole process, avoiding changes that might compromise the energy efficiency and the desired quality of the final product – the building.

2 CONTEXT

This paper is based on case studies of residential buildings in Portugal, built in the light of Portuguese regulations on energy performance of buildings (after 2008). In this sense it is necessary to understand the legal context in which energy performance of buildings is addressed and implemented, the framework of procedures and the main stakeholders involved, as well as social, economic and cultural aspects influencing the practice of designers and builders.

Following the publication of the 2002 European Energy Performance of Buildings Directive (2002/91/EC), Portugal issued, in 2006, two regulations on energy performance and air quality of buildings: one for residential buildings and service buildings without centralized HVAC systems - the Regulation of Thermal Behavior Characteristics of Buildings (RCCTE); and another for buildings with centralized HVAC systems - the Regulation of Energy Systems of Acclimatization in Buildings (RSECE). These regulations apply for new buildings and for existing buildings subject to major renovations.

With these regulations, the national Energy Certification System (SCE), was also created, in 2006, launching Energy Performance Certificates (EPC) with effect for new housing buildings starting January 2008, and from January 2009 also for existing buildings. The SCE contemplates two stages for certification of new buildings: the design stage, where the project for thermal performance (RCCTE or RSECE) must be accompanied by a Declaration of Statutory Conformity, which ensures that the regulations are correctly applied, and defines the expected energy performance of the building; and the conclusion of construction stage, where the EPC is issued.

The project for thermal performance is submitted with the other specialty projects (engineering), accompanying the architecture project. This is demanded by law in order to get the building permit. So, it is made before the beginning of construction.

In the present case, as we are focusing the study on residential buildings, the regulation applied is the first (RCCTE). This regulation defines maximum energy needs for heating, cooling and production of domestic hot water (DHW), as well as maximum primary energy needs. It also enforces the use of renewable energy sources for DHW, namely solar panels, whenever there is adequate solar exposure area. The regulation defines maximum values for heat transfer coefficients for the building´s shell, and maximum values for the solar factor of windows (g-value). The systems used to suppress the building´s needs for heating, cooling and DHW, their efficiency and the type of energy used, are accounted for in the final balance of primary energy needs and have a direct influence in determining the energy performance of the building, related to CO_2 emissions.

The project for thermal performance is made by civil engineers or architects, but the certification process can only be applied by qualified experts, which must attend courses and pass a national exam to be acknowledged.

Despite all the regulations and procedures, there are still flaws along the process. In most cases, what is predicted in the design stage is different from the final result. So what changes, why and who is accountable for this?

3 METHODOLOGY

Through the analysis of case studies of residential buildings in Portugal, from design stage to end of construction, we identify the critical moments when changes to the initial project are made, the reasons and stakeholders involved. The changes reported are those with direct influence on the energy performance of the building, and represent alterations to the project of thermal behavior, the base-project in this matter.

Three case studies were selected, which were found representative of the most common types of residential buildings and interventions, and have a high energy performance. This selection also took in account the nature of the investors.

The project´s assumptions in matter of thermal comfort and energy performance (energy indicators for heating, cooling, DHW and primary energy needs); the construction solutions for the building´s shell and windows; the systems for acclimatization and DHW; and the use of renewable energy systems are analyzed. Then the final results after construction are compared with the project, identifying the differences.

Analyzing the encountered differences, the reasons that lead to these changes, and the stages in which they occur are identified, by talking to the main stakeholders – the architect; the thermal behavior's project designer and certification expert; the technical director of construction work; and the promoter/investor.

Crossing the results, the critical points of the process where improvements have to be made, are identified, providing a starting point for the developing of best practices and long-term thinking on the design and construction processes towards nearly Zero-Energy Buildings.

4 CASE-STUDIES

Three buildings were selected for the present study:

- Single house – detached, new. Private investor (home owner)
- Single house – in block, subject to major renovation. Private investor (home owner)
- Apartment building – multi-storey, new. Real estate developer.

The characteristics of the buildings, at design stage and after completion, are described on the tables below.

In the calculation of primary energy needs, the conversion factor for electricity is 0.29 kgep/kWh, and for gas is 0.086 kgep/kWh. Acclimatization is considered only 10% of the time. When systems are not installed, default values are used in calculations (RCCTE).

4.1 *Reference building No.1*

Table 1: Characterization of reference building No.1 (part 1)

Location	Sintra	
Description	3 storey house: basement for parking and storage; 2 floors with living room, kitchen, 4 bedrooms and 4 bathrooms.	
Geometry	Net area	207.50m2
	Room height	2.40 m
Heating (Climate zone I1. Degree-days = 1430ºC.days; Duration: 6 months)	System	Air conditioning with COP of 4
	Reference indoor temperature	20ºC
	Calculated needs (Nic)	53.5 kWh/m2.yr
Cooling (Climate zone V1N. Outdoor temperature 19ºC)	System	Air conditioning with EER of 3
	Reference indoor temperature	25ºC
	Calculated needs (Nvc)	7.2 kWh/m2.yr
DHW (40l/person/yr at 45ºC)	Solar system	4.9 m2, vacuum tube, South oriented, 44º tilt angle, full expose. 300l water tank in garage. 3183 kWh.yr
	Support system	Gas boiler with 78% efficiency
	Hot water use	5 occupants = 200l
	Calculated needs (Nac)	8.3 kWh/m2.yr
Ventilation	Natural	0.90 ren./hr
Primary energy needs (ntc)		2.3 kWh/m2.yr
CO2 emissions		0.6 Ton/year
Energy Class		A

Table 1: Characterization of reference building No.1 (part 2)

Differences found after completion of construction		
Heating	System	Not installed.
	Calculated needs (Nic)	52.1 kWh/m2.yr*
Cooling	System	Not installed.
	Calculated needs (Nvc)	7.6 kWh/m2.yr*
DHW	Solar system	7.8 m2, vacuum tube, South oriented, 45º tilt angle, full expose. 500l water tank in garage. 3582 kWh.yr
	Support system	Not installed.
	Calculated needs (Nac)	19.2 kWh/m2.yr
Ventilation		No changes
Primary energy needs (ntc)		3.2 kWh/m2.yr
CO2 emissions		0.8 Ton/year
Energy Class		B

*Differences due to small changes on dimensions of windows

This building has a constructive solution not very common in Portugal. It's an all concrete building, with 20cm external concrete walls, insulated on both sides with 3.7cm of high density expanded polystyrene (EPS), covered by plaster. The inside walls are in brickwork, covered with plaster. Roofs and floors are also in concrete. The roofs are highly insulated on the outside with 4cm of extruded polystyrene (XPS) and 10cm of lightweight expanded clay, and have plasterboard false-ceilings on the inside, also insulated with mineral wool.

The windows have double glazing with low emission 4mm glass on the inside, 12mm air space, and laminated 8mm glass on the outside. Solar factor of glazing (g-value) of 0.56, which is the maximum admitted for summer by the regulations. Some windows have inside curtains, lowering their g-value to 0.28.

The construction solutions were proposed by the builder and structural designer, and accepted by the owner because they were 25% cheaper than traditional solutions and highly resistant to earthquake. Architect and thermal project designer were only called to agree.

Table 2: Decision stages and stakeholders - building No.1

Stakeholders		Architect	RCCTE designer	Other specialities/ engineers	Builder/ supplier	Investor
Design stage	Building shell	Ok	Ok	• Civil eng.	• Builder	Ok (cheaper + resistant)
	Heating		Ok (default)			• (Comfort)
	Cooling		Ok (default)			• (Comfort)
	DHW solar		• (RBL)			Ok
	DHW support		Ok	• (RBL)		Ok
Building stage	Building shell	No changes				
	Heating				• Supplier	Ok (cost vs. quality)
	Cooling				• Supplier	Ok (cost vs. quality)
	DHW solar				• Supplier	Ok (costs + technical)
	DHW support				• Supplier	Ok (costs + technical)

• - Decision maker; Ok – Called to agree; RBL – Required by law

Table 2 shows who the main stakeholders were in each stage. Who made the decisions (marked with "•"), and who was only called to agree. The reasons behind the decisions are also pointed (in brackets).

4.2 *Reference building No.2*

Table 3: Characterization of reference building No.2

Location	Lisbon	
Description	5 storey house: basement for storage; ground floor for parking; 2 floors with living room, kitchen, 3 bedrooms and 3 bathrooms; open attic for working (office).	
Geometry	Net area	158.50m^2
	Room height	2.20 m
Heating (Climate zone I1. Degree-days = 1430ºC.days; Duration: 6 months)	System	Air conditioning with COP of 4
	Reference indoor temperature	20ºC
	Calculated needs (Nic)	48.9 kWh/m^2.yr
Cooling (Climate zone V1N. Outdoor temperature 19ºC)	System	Air conditioning with EER of 3
	Reference indoor temperature	25ºC
	Calculated needs (Nvc)	14.2 kWh/m^2.yr
DHW (40l/person/yr at 45ºC)	Solar system	3.9 m^2, vacuum tube, South oriented (-4º), 28º tilt angle, partial exposure (shading SE). 300l water tank in attic. 2173 kWh.yr
	Support system	Gas boiler with 87% efficiency
	Hot water use	4 occupants = 160l
	Calculated needs (Nac)	11.3 kWh/m^2.yr
Ventilation		0.85 ren./hr
Primary energy needs (ntc)		1.5 kWh/m^2.yr
CO2 emissions		0.3 Ton/year
Energy Class		A
Differences found after completion of construction		
Geometry	Net area *	234.50m^2
	Room height	2.36 m
Heating	System	Radiant floor, heat pump with COP of 3.94
	Calculated needs (Nic)	35.7 kWh/m^2.yr*
Cooling	System	Radiant floor, heat pump with EER of 3.67
	Calculated needs (Nvc)	15.3 kWh/m^2.yr*
DHW	Solar system	4.6 m2, vacuum tube, South oriented (-4º), 28º tilt angle, partial exposure (shading SE). 200l water tank in attic. 2333 kWh.yr
	Support system	Heat pump with COP of 2.6
	Calculated needs (Nac)	1.2 kWh/m2.yr**
Ventilation		0.70 ren./hr*
Primary energy needs (ntc)		0.7 kWh/m^2.yr**
CO2 emissions		0.2 Ton/year
Energy Class		A+

*Differences due to major changes on construction solutions, windows and net area (due to ac-climatization of basement).
**Differences due to changes on systems

This building is an original construction from the 19th century, subject to major renovation, located in the heart of the city. The existing facades, in ordinary stone masonry, could only be maintained in the ground floor and a new concrete structure was made. In the end, current traditional solutions were adopted, with 40cm external double brick walls, insulated on the cavity with 4cm of XPS, and covered by plaster. Inside walls are in brickwork, covered with plaster, or in plasterboard, with mineral wool on the inside. Pillars and beams are insulated on the outside with 6cm of EPS. Roof and floors are in concrete. The house has a pitched roof with a 12cm concrete slab, insulated on the outside with 4cm of XPS and covered with roof tiles. All the floors are insulated with 5cm of EPS due to the installation of radiant floor.

The windows are in PVC and have double glazing with 4mm glass on the inside, 14mm air space, and 5mm glass on the outside. Solar factor of glazing (g-value) of 0.65. All windows have wood shutters on the inside, lowering their g-value to 0.46. The house faces north and has a back front to south. It is inserted in a block, with adjacent houses on both sides, reducing losses by the building´s shell.

Although the choice of the constructive solutions for the building´s shell was initially made by the architect, they were changed by the builder, more comfortable with traditional solutions (Table 4). The thermal performance designer and the energy performance expert were not called upon to rule about these changes.

Table 4: Decision stages and stakeholders - building No.2

Main Stakeholders		Architect	RCCTE designer	Other specialities/ engineers	Builder/ supplier	Investor
Design stage	Building shell	•	Ok	Ok		Ok
	Heating		Ok			• (Comfort)
	Cooling		Ok			• (Comfort)
	DHW solar		• (RBL)			Ok
	DHW support		Ok	• (RBL)		Ok
Building stage	Building shell	Ok			• Builder	Ok
	Heating				• Supplier	Ok (cost vs. quality)
	Cooling				• Supplier	Ok (cost vs. quality)
	DHW solar				• Supplier	Ok (costs + technical)
	DHW support				• Supplier	Ok (costs + technical)

• - Decision maker; Ok – Called to agree; RBL – Required by law

4.3 *Reference building No.3*

This building is a unique situation in the group, because the project was prior to the implementation of the regulations. The developer wanted a high quality building, investing on thermal and acoustic behaviour. He hired experts to review the project and provide solutions for the building´s shell. These experts worked with the developer, the architect, the builder and other experts, before and during construction. All solutions for materials and systems were discussed with the developer and the suppliers, with the experts´ feedback, helping to choose the best quality-price options (Table 6).

The building has ventilated facades, with 40cm external double brick walls, insulated on the outside with 4cm of XPS, and covered by stone slabs or phenolic panels. The inside walls are in brickwork, covered with plaster. Roof and floors are in concrete. The last floor has a pitched roof with an 18cm concrete slab, insulated on the outside with 10cm of XPS and covered with metal panels.

The windows are in aluminium with thermal break and have double glazing with 6mm bronze glass on the inside, 12mm air space, and 5mm glass on the outside. Solar factor of glazing (g-value) of 0.5. Most windows have inside blinds, lowering their g-value to 0.25. The building faces south and has a back front to north. It is inserted in a block, with adjacent houses on both sides, reducing losses by the building´s shell.

Table 5: Characterization of reference building No.3

Location	Lisbon	
Description (building)	9 storey apartment building: 2 basements for parking; ground floor for commerce; 6 floors with 2 apartments each (1 bedroom and 2 bed-room).	
Description (apartment)	Apartment with living room, kitchen, pantry, 2 bedrooms and 2 bath-rooms.	
Geometry	Net area	$111.50m^2$
	Room height	2.40 m
Heating	System	Air conditioning with COP of 4
(Climate zone I_1. Degree-days = 1190ºC.days; Duration: 5,3 months)	Reference indoor temperature	20ºC
	Calculated needs (N_{ic})	30.0 kWh/m^2.yr
Cooling	System	Air conditioning with EER of 3
(Climate zone V_{2S}. Outdoor temperature 23ºC)	Reference indoor temperature	25ºC
	Calculated needs (N_{vc})	12.2 kWh/m^2.yr
DHW	Solar system	No possible. Not enough roof area with exposure.
(40l/person/yr at 45ºC)	Support system	Gas boiler with 89.4% efficiency
	Hot water use	3 occupants = 120l
	Calculated needs (N_{ac})	25.9 kWh/m^2.yr
Ventilation	Natural	0.80 ren./hr
Primary energy needs (n_{tc})		2.6 kWh/m^2.yr
CO2 emissions		0.3 Ton/year
Energy Class		B
Differences found after completion of construction		
Heating	System	Only pre-installation.
Cooling	System	Only pre-installation.
Primary energy needs (ntc)		3.2 kWh/m2.yr
CO2 emissions		0.4 Ton/year
Energy Class		B*

***** Only because it was not possible to install solar panels for DHW.

Although it has the lower energy class of the set (B), due to the fact that it doesn´t have solar panels for DHW, this is the best example of good coordination and intervention of all major stakeholders.

Table 6: Decision stages and stakeholders - building No.2

Main Stakeholders		Archi-tect	RCCTE designer	Other speci-alities/ engi-neers	Builder/ sup-plier	Investor
Design and building stage	Building shell	•	•	Ok		•
	Heating	Ok	Ok			• (Comfort)
	Cooling	Ok	Ok			• (Comfort)
	DHW solar	Not possible due to little roof area with exposure. Should have been pre-dicted at design stage				
	DHW support	Ok	•	Ok		•

• - Decision maker; Ok – Called to agree; RBL – Required by law

5 CONCLUSIONS

Looking at the case studies it is clear that the decisions regarding constructive solutions and systems applied to the building are made mainly by builders and suppliers, negotiating directly with the investors.

The main motivations for changes during the process are technical reasons, invoked by the builders (most of the times by their own interest and lack of knowledge), and economical reasons, invoked by the investors. The architect, who should be the project´s coordinator, is left out of negotiations most of the time. This is even more common with private investors, building for themselves, who are willing to invest in the quality of their homes and in good systems for heating, cooling and DHW, but have little technical knowledge and are highly supple. Moreover, in the residential sector and especially in single housing buildings, builders have still little knowledge of all the aspects that influence the energy performance of buildings, and are still clinging to traditional solutions that no longer fulfil the requirements. Only well informed investors seek advice with experts in the area, in order to find the best solutions between energy performance and cost-optimal.

The energy performance aspects are still relegated for the end of construction and very much connected with the systems used for acclimatization and DHW. This is also a consequence of the regulations, which empower these aspects in the calculation of the energy class. The quality of construction solutions and of the design is most of the times underrated.

There is still a long way to go as most of the stakeholders have still little knowledge on the aspects that can condition the energy performance of buildings. Among the most common mistakes found were the difficulty on understanding the building´s shell as the most important element in the building, conditioning it´s energy performance; understanding the need for proper shading of windows; proper dimensioning of heating, cooling and DHW systems; resistance to use solar panels for DHW (due to high cost and low confidence in performance); resistance to embrace new construction solutions and materials and adequate use of passive solutions at the design stage.

To fulfil the demanding requirements for nZEB, architects and all the stakeholders must have an active role, starting with the design, and in all stages. This requires deep knowledge of the aspects that influence the energy performance of buildings, which are still neglected. Continuous collaboration between architects, designers and experts on energy performance of buildings, during all stages, is crucial to achieve the nZEB goal. In this sense is imperative that all the stakeholders are aware of the importance of energy performance of buildings, the incoming challenge of nZEB, and gain knowledge in this area. Only with the collaboration of all stakeholders, well informed and well coordinated, in all stages, it will be possible to achieve nearly zero-energy residential buildings in Portugal by 2020.

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Cost optimality and nZEB target in the renovation of Portuguese building stock. Rainha Dona Leonor neighborhood case study

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ABSTRACT: Improving energy efficiency in existing buildings is a great challenge. These buildings have their own limitations related with their design, location and function. To study the possibilities of cost-effectively improve the thermal performance of these buildings and increase the chances of reaching the nearly zero energy (nZEB) target, one building of Rainha Dona Leonor neighborhood has been analyzed. The purpose of the study was to find the most cost-effective renovation solution for this case study and assess in what way this solution contributes to reaching the nZEB target. With this work it was possible to understand that the energy performance of this kind of buildings can be firstly improved through renovation measures applied to the envelope but, above a certain level, changing the existing equipment and the energy source become more cost-effective.

1 INTRODUCTION

Buildings are responsible for 40% of total energy consumption and 36% of CO_2 emissions in Europe (BPIE, 2011).

In order to try to stop the increase of carbon emissions in the building sector, the EU Directive EPBD (European Parliament, 2010) introduced the nearly Zero Energy Buildings concept (nZEB) and established its mandatory implementation for new buildings after the end of 2020. These buildings present very high energy performances with very low energy needs that are to be satisfied with renewable energy sources harvested on-site (BPIE, 2011).

Besides the nZEB target, EPBD also requires that buildings are cost-effective during their life cycle and established a methodology for the cost-optimal calculations. The outcome of cost-optimal level shall include macroeconomic and financial calculations. The macroeconomic calculations take into account the carbon emissions costs, while the financial calculations only consider the investors costs (Diacon & Moring, 2013). Within this study, only the financial perspective is shown.

Apart from the type of energy source, the achievement of the nZEB target in buildings usually involves high levels of insulation, very efficient windows, good levels of air tightness and controlled ventilation (BPIE, 2011).

There are some renewable energy sources that can be used in buildings such as photovoltaic, solar thermal, wind, hydroelectricity and biofuels (Pless & Torcellini, 2010). However, some of these solutions cannot be applied to every building. Existing buildings face several barriers when it comes to refurbishment and even more when the target is nZEB. This gets even more difficult when the building is part of social housing. In Europe, social and public housing providers own and manage 12% of the housing stock (Diacon, 2013). Buildings belonging to social housing face severe economical, technical, legislative, social and organizational barriers. The lack of money, the split incentives and poverty are the main economic barriers to building renovation in social housing (Diacon, 2013). These buildings are usually rented to poor people and so, the rents should be kept at reasonable levels (Diacon, 2013).

Social buildings providers usually support the residents who are normally amongst the most vulnerable groups in society. Therefore it is important to build capacity and confidence amongst these providers towards the 2020 requirements for buildings, once they have an important role in the renovation processes (Diacon & Moring, 2013).

2 METHODOLOGY

To understand the potential of reaching the nZEB level in the renovation of Portuguese buildings, a case study was analyzed. This case study is part of a social housing neighborhood in Porto called Rainha Dona Leonor. This neighborhood has multifamily buildings and blocks of apartments. The renovation intervention started with the renovation of the multifamily buildings. Part of the neighborhood has already been submitted to renovation and based on the chosen renovation solution, the cost optimal levels were identified and it was analyzed in what way it is possible to reach a building with zero carbon emissions and net zero energy needs.

The first step was to analyze different renovation measures concerning the insulation of the buildings envelope and the buildings systems. For the chosen case study, different scenarios were tested, involving improvements in the building envelope and also the replacement of the heating/cooling and DHW systems. A life cycle of thirty years was considered, taking into account the replacement of the equipment after twenty years and considering its residual value in the end of this period. The alternatives considered for the equipment were HVAC for heating/cooling and an electric heater with storage tank and solar panels for DWH, gas boiler for heating/DHW and HVAC for cooling, heat pump for heating/cooling and DHW and HVAC for heating/cooling with a biomass boiler for DHW.

The base for the calculations was the cost-optimal methodology proposed by the European Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing the Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings as well as the Guidelines accompanying the Commissions Delegated Regulation No 244/2012 (European Commission, 2012 a) and b)).

The energy needs were calculated according to the Portuguese legislation that regulates the residential buildings thermal performance (RCCTE, Decree-Law 80/2006) in accordance with ISO – 13790 and primary energy was calculated in accordance with the proposed recast for the Portuguese thermal regulation considering total energy needed to deal with all the energy needs, and considering conversion factors of $2.5kWh_{PE}/m^2.a$ per $kWh/m^2.a$ for electricity and $1kWh_{PE}/m^2.a$ per $kWh/m^2.a$ for gas. The indoor comfort temperatures considered were 20ºC for winter and 25º for summer.

The costs were calculated with the Cype® software for generation of construction prices (http://www.geradordeprecos.info/). The energy costs used in the study were based on the Portuguese energy costs and it has been considered the scenario given by the European Commission (European Commission, 2012b)) for the estimation of the energy prices evolution in the near future.

After assessing the cost-optimal solutions for each one of the equipments considered, it was calculated the needed contribution of the photovoltaic panels for reaching the zero energy level. For this it was used the European Commission's Photovoltaic Geographical Information System (PVGIS) (http://re.jrc.ec.europa.eu/pvgis/). The different renovation measures considered in the study are presented in Table 1. The renovation measures are separated by the systems used for heating, cooling and DHW preparation. For each system there are different combinations of measures to improve the building envelope that together form different renovation scenarios (Sn). In all, thirteen scenarios were analyzed. The base scenario (B) is the adopted renovation solution for this case study. Scenario 8 (S8) and 10 (S10) are similar but the windows have different U-values.

Table 1 Summary of the different renovation measures considered in the study

Heating/cooling/DHW	Scenario	Walls	Roof	Window	Glass
HVAC + electric heater with storage tank + Solar panels (except B)	B	EPS 6cm	XPS 5cm	wood	simple
	S1	EPS 8cm	XPS 8cm	PVC	double
	S2	EPS 10cm	XPS 10cm	PVC	double
	S3	EPS 12cm	XPS 12cm	PVC	double
Gas boiler	S4	EPS 5cm	XPS 5cm	wood	simple
	S5	EPS 8cm	XPS 10cm	PVC	double
	S6	EPS 12cm	XPS 12cm	PVC	double
Heat pump	S7	EPS 6cm	XPS 5cm	wood	simple
	S8	EPS 8cm	XPS 8cm	PVC	double
	S9	EPS 12cm	XPS 12cm	PVC	double
	S10	EPS 8cm	XPS 8cm	PVC	double
Biomass boiler + HVAC	S11	EPS 6cm	XPS 5cm	wood	simple
	S12	EPS 8cm	XPS 10cm	PVC	double
	S13	EPS 12cm	XPS 12cm	PVC	double

3 CASE-STUDY

The case study is a building from the social housing Rainha Dona Leonor neighborhood. It was built in the fifties and it is located in Porto, northwest of Portugal.

The renovation intervention took place on the smaller multifamily buildings of the neighborhood. These buildings have two floors and different indoor partitions, varying the number of rooms per apartment.

The buildings had very small areas and were already in decadent living conditions. Due to the small interior areas, users also added exterior compartments to support peoples' life style. These elements negatively changed the initial appearance of the neighborhood. So, the surrounding areas of the buildings were also improved to recover the initial identity of the neighborhood.

The building under analysis is a semi-detached house. It used to have four apartments with two rooms each. The envelope did not have any insulation and there were wooden window frames with simple glazing and external plastic shutters. The system for DHW production was an electric heater with storage tank and there were no heating/cooling systems apart from portable electric heaters or fan coils.

The renovation project aimed at increasing indoor living areas, improving thermal insulation and replacing systems.

Figure 1 shows the building before and after the renovation process. Table 2 shows the thermal characteristics of some of the building components before the renovation process, namely the U-values and the reference U-values in the Portuguese thermal regulation, as well as the efficiency of the systems for heating and DHW preparation. The initial heating needs of this building were 119,7kWh/m².a, the cooling needs 6,5kWh/m².a and DHW needs 37,1 kWh/m².a.

Figure 1 Building before and after renovation on Rainha Dona Leonor neighborhood

Table 2 Thermal characterization of the Building before renovation

Element	Area (m²)	U – Value before renovation (W/m².ºC)	U – Value reference values (W/m².ºC)	η (efficiency)
Exterior walls	141,00	1,38/1,69*	0,60	–
Windows	16,93	3,40	3,30	–
Roof	73,79	2,62	0,45	–
Floor	61,80	2,50	0,45	–
DHW	–	–	–	0,85
Heating	–	–	–	1

* The 1st value is for the first floor and the 2nd for the second floor

3.1 *Renovation process*

In this study, the base solution corresponds to the renovation solution really implemented in the building. This solution includes ETICS with a 6 cm thick layer of EPS in the exterior walls, XPS with 5 cm in the roof, wooden frames windows with double glazing and a new electrical water heater with storage tank. For heating and cooling the usable space, the renovation solution considered a HVAC system with multi-splits for the rooms and living room. It also includes solar panels for DWH preparation.

Table 3 shows the energy needs, the primary energy use and carbon emissions for the initial situation of the building (before renovation) and considering the above mentioned renovation solution (after renovation).

Table 3 Summary of energy needs and carbon emissions before and after renovation

	Heating needs (kWh/m².a)	Cooling needs (kWh/m².a)	DHW (kWh/m².a)	Primary energy use (kWh/m².a)	Emissions (Ton eq CO_2)
Before renovation	119,7	6,5	37,1	413,7	18,9
After renovation	68,5	7,9	27,1	127,2	5,8

Taking this renovation solution as base solution and analyzing the cost-optimal solution for the alternative renovation scenarios, the results for the financial calculations are presented in figure 2. This figure shows a graphical result with the primary energy for each scenario and its global cost. Each group of points represents different equipment and the lower point of each group is the cost-optimal solution for that equipment. The cost-optimal solutions are S2 for HVAC with electric heater and solar panels for DHW preparation, S5 for the gas boiler, S8 for the heat pump and S12 for biomass boiler.

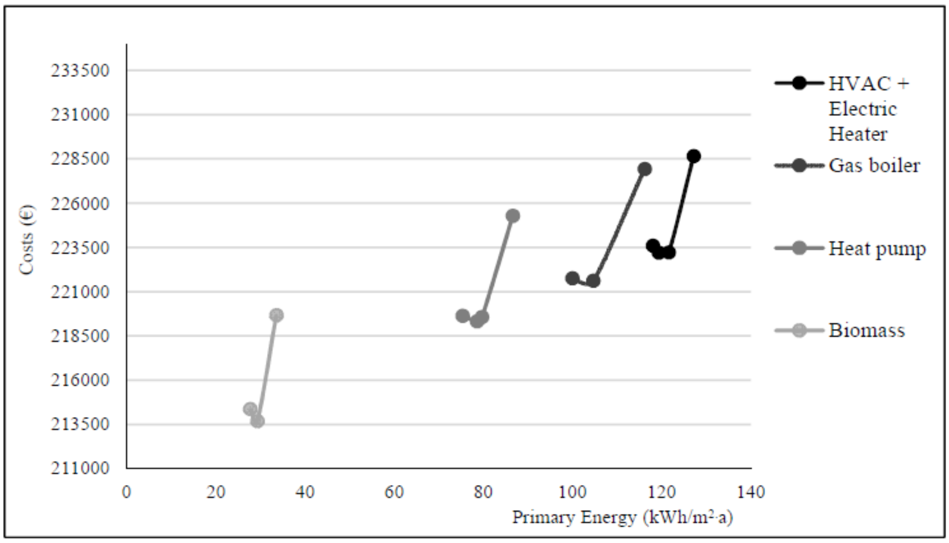

Figure 2 Global costs for each one of the alternative scenarios regarding primary energy use

Among all the scenarios, the cost-optimal solution is S12 corresponding to a biomass boiler for heating the living room and preparation of DHW and a HVAC system in the rooms. The U – value for the walls is 0,37/0,39 W/m².ºC, for the roof is 0,34 W/m².ºC and for the windows is 2,4 W/m².ºC. The boiler efficiency is 91%. This solution leads to primary energy needs of 29,3 kWh/m².a, which is 30% of the primary energy needs of the base solution (B). Table 4 shows the comparison between the U-values for the base solution, the cost-optimal solution and the Portuguese reference values.

Table 4 Comparison between the U-values for the base solution, the cost-optimal solution and the Portuguese reference values

Element	U – Value after renovation (W/m².ºC)	U – Value cost optimal solution (W/m².ºC)	U – Value Reference values (W/m².C)
Exterior walls	0,45/0,48*	0,37/0,39*	0,60
Roof	0,34	0,34	0,45
Windows	3,90	2,40	3,30

* The 1st value is for the first floor and the 2nd for the second floor

Figure 3 shows the costs disaggregation for each one of the analyzed solutions. On figure 3, the costs start above zero because the basic works necessary to the renovation process with the same value in every analyzed solution have been left out of the comparison. Based on the graphic, the most cost-effective equipment is the biomass boiler. Considering the other three equipments, the balance between the systems costs, renewable costs and energy costs result in a similar value and the maintenance cost are the ones responsible for the main differences between the solutions. Besides this and excluding the renewable costs, the systems costs and the energy costs are inversely related. The increase of the costs of the envelope, regardless the system used, does not exceed 1700 euros which corresponds to 16% of the base envelope solution costs.

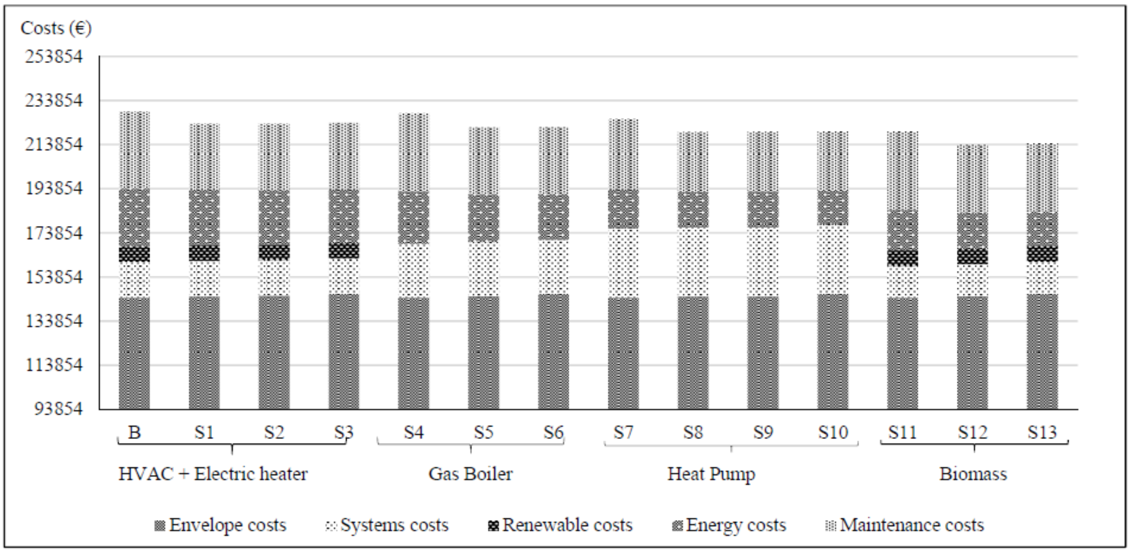

Figure 3 Disaggregated costs of the analyzed solutions

Figure 4 shows the carbon emissions, for each one of the alternative scenarios. This figure is similar to figure 2 because the primary energy is proportional to the carbon emissions, so the renovation solutions follow the same trend.

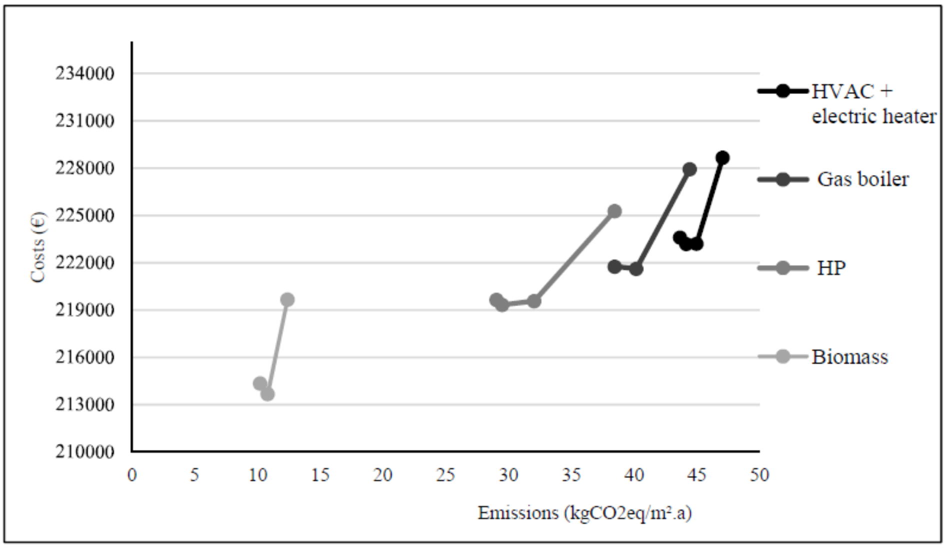

Figure 4 Global costs for each one of the alternative scenarios regarding carbon emissions

3.2 *Renovation process towards net zero energy level*

Another objective of this work consisted in assessing how the net zero energy level and the zero emissions level could be achieved. For this case-study, and taking into consideration the renovation scenarios mentioned before, the net zero energy level and the zero carbon emissions level were achieved considering the contribution of photovoltaic panels.

Figures 6 and 7 show the results obtained, in terms of energy, with the contributions of photovoltaic panels for each one of the analyzed measures. Each figure represents the results for each one of the combinations taken into account heating, cooling and DWH preparation, with and without photovoltaic panels. Each different marker on graphic represents one scenario, with and without photovoltaic panels to reach zero balance between the use of primary non-renewable energy and the on-site generation of energy from renewable sources. Analyzing the graphics it is possible to observe that most scenarios do not have significant changes with the addition of the photovoltaic panels in terms of cost-optimal level. But with the increase of the costs related to the photovoltaic panels, the cost-optimal solution for the gas boiler and biomass boiler gets closer to the other scenarios.

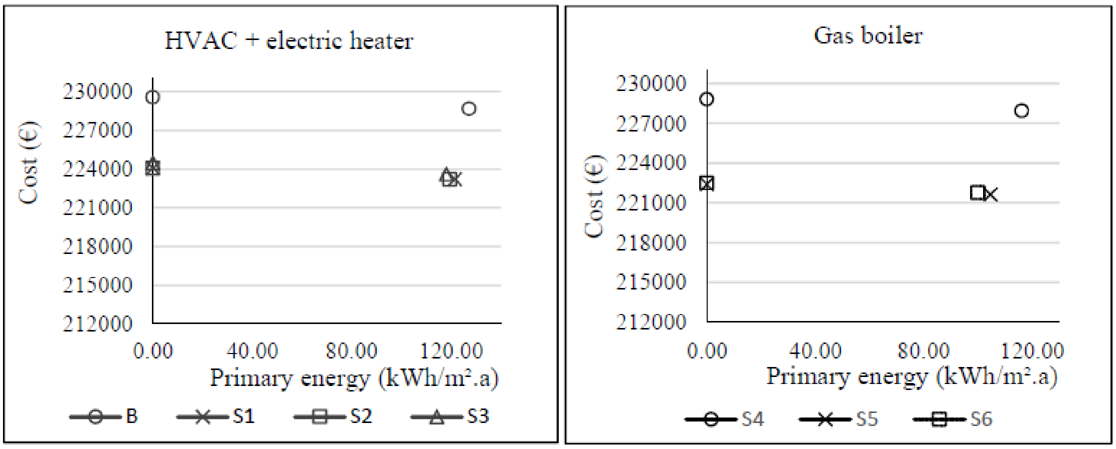

Figure 5 Results with photovoltaic panels for HVAC + Electric heater and for the Gas boiler

In Figure 5, the cost-optimal solution for HVAC with the electric heater for DHW preparation corresponds to the square marker and it corresponds to scenario 2 (S2). This solution has ETICS with 10 cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC windows with double glazing. The U-values are 0.31/0.32 W/m². ºC for the exterior walls, 0.34 W/m².ºC for the roof and 2.4 W/m².ºC for the windows. For the gas boiler the cost-optimal solution is the X marker and it corresponds to scenario 5 (S5). It has ETICS with 8cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC window frames with double glazing. The U-values are 0.37/0.39 W/m². ºC for the exterior walls, 0.34 W/m². ºC for the roof and 2.4 W/m². ºC for the windows. The inclusion of the photovoltaic panels does not change the cost-optimal solution for these two systems.

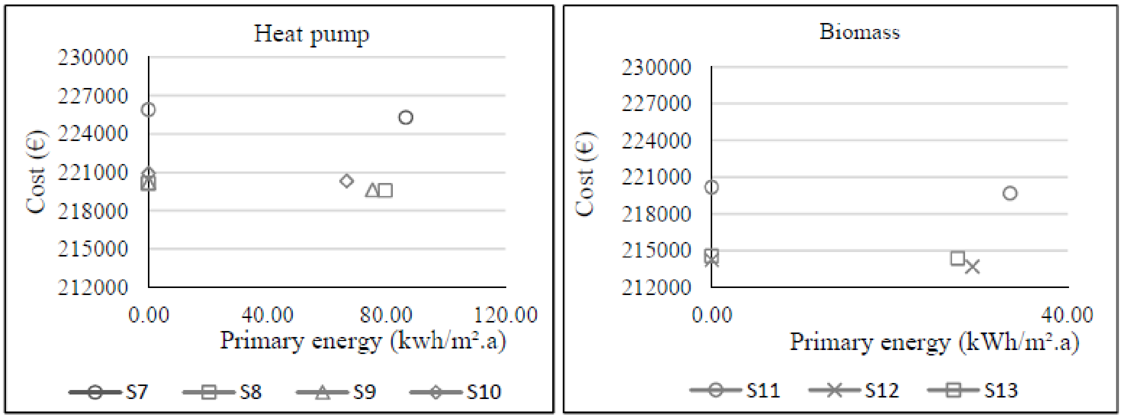

Figure 6 Results with photovoltaic panels and heat pump and biomass boiler

In Figure 6 the cost-optimal solution for the heat pump corresponds to scenario 8 (S8) and it is represented by the square marker. This solution included ETICS with 8 cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC window frames with double glazing. The U-values are 0.37/0.39 W/m². ºC for the exterior walls, 0.42 W/m². ºC for the roof and 2.4 W/m². ºC for the windows. For the biomass boiler the cost-optimal solution is scenario 12 (S12) which corresponds to the cost-optimal solution for this building. The addition of photovoltaic panels does not have impact on the cost-optimal solution for these two systems.

4 CONCLUSIONS

Despite the specific restrictions of this building renovation process, it is already possible to take some conclusions on how the Portuguese building stock can cost-effectively move towards more energy efficient buildings. The calculation of the cost optimal levels in Portugal depends on the location, age of the building and on its construction techniques and materials, as well as on the buildings type.

The cost-optimal levels calculations show that the most cost-effective renovation solution includes a small biomass boiler for heating (partially) and DHW preparation and a multi-split HVAC system for cooling and to assure the remaining heating needs. The optimal levels for the building envelope are in accordance with the current reference values of the Portuguese legislation.

The evolution of this packages of measures towards the zero energy goal with the addition of photovoltaic panels for energy production, doesn’t affect the optimal solution with the financial calculation remaining the same whatever the equipment considered. In some cases the global costs of the cost-optimal solutions with photovoltaic panels gets closer to solutions with higher level of insulation. Even though the cost optimal package hasn’t change in the group of tested packages, this is an indicator that in these cases a slight increase of insulation beyond the cost optimal level should be analysed.

As so, the cost-optimal methodology for this building provides identical results for the analysis of renovation solution without energetic consumption restrictions and with renovation solutions using photovoltaic panels to reach a zero energy balance for heating, cooling and domestic hot water preparation.

Unlike initial expectations, considering the current prices of photovoltaic panels and the trade of electricity with the grid at equal prices, there were no relevant changes in the optimal solutions, when the main target is the zero energy balance.

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Energy Performance of a Galician Hostel

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ABSTRACT: The research poses a simple question, ‘How are the CO2 emissions in a Saint James way hostel? Is there any simple way to improve it? ‘In order to answer this question a study of energy consumption levels and CO2 emissions in two Galician hostels of Saint James Way has been carried out through monthly billing consumption. Some factors that influence this energy use such as variety of users, collective rooms and the need of ventilation are reviewed. The worst performing one, “Ribadiso de Abaixo” was then monitored, deeply analyzed and some methods to reduce its consumption were proposed.

1 INTRODUCTION

1.1 *Context*

The main pilgrimage route of Europe is “Saint James Way”, world heritage route towards the Cathedral of Santiago de Compostela (Spain). Among the several options the main way goes through France and Spain (Fig. 1). Tradition says that the remains of the apostle Saint James are buried there and it is still possible to follow these medieval routes up to his tomb. But not only religion can be the reason to get involved into this kind of adventure. The way goes through some of the most beautiful, historic and interesting countryside areas, before arriving in the distinctive Celtic region of Galicia, bordering the Atlantic.

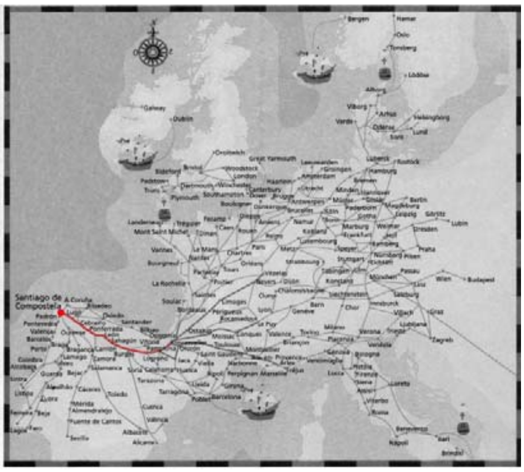

Figure 1.Saint Jacques way routes

Figure 2.Example of abandoned house

Hostels provided to the pilgrims to spend the night may be private or public. Most of the public ones are carried out through the refurbishment of constructions along the way that are unused or in bad conditions (Fig. 2). This is the case of the two hostels chosen to study within the Galician context:

- “Casa de la Torre” in Redondela (urban context).
- “Ribadiso hostel” in Arzúa (middle of the countryside).

Due to the lack of studies about energy consumption in hostels, both of them were analyzed through billing consumption in order to assess their CO_2 emissions. The one in Ribadiso de Abaixo was also monitored for one week to understand deeper its performance and think of possible ways of improvement.

1.2 *Hostel Characteristics*

The number of registered pilgrims last year was 12. 385 and this number increases surprisingly fast, around 23% a year. During the peak periods, people can even spend the night in the floor of any sport facilities or other public buildings supplied by the councils due to the lack of accommodation. Therefore, there is a need of more hostels due to this situation.

One of the most common strategies is to use the historical buildings nearby the way creating new spaces of opportunity. Refurbishments bring changes in technical parameters such as ventilation rates, occupancy levels, internal gains, thermal response…and the subsequent change in energy consumption levels. The main challenge is to adapt the preexisting building to the new needs in order to optimize the performance. Hostels can be defined as a typology half-way between housing and hotel. But there is also a need of extra space, common areas, acoustic control and effective ventilation systems in order to improve the quality of the air.

The main differences between the pilgrimage hostels and other accommodation types are:

-Collective rooms: One of the main characteristics of this kind of spaces is that there are communal rooms with a huge range of sizes. These tend to be collective and mix used with all the rest of the spaces in the building (kitchen, dining room and bathrooms) to be shared.

-Variety of users: The normal age range is between 18-70 years old, but people from every age and condition can do it. Some data collected in “Saint Jean du Pied du Port”, South France, revealed that 51% use to be men and 49% women. This is translated into different comfort zones and personal conditions combined into the same space.

-Need of ventilation: Normally 88% does it walking while the 12% left by bike. After several hours walking of physical activity the transpiration of the human body achieves high rates and therefore the need for ventilation and fresh air in these areas is important. On this matter, the reduced window to floor ratio that normally has vernacular architecture can become a problem. On the other hand low daylight levels become a secondary issue because pilgrims use these areas mainly to rest during the evening and night periods.

Thus, the requirements of the new use, the inherent properties of the building and the technical options in the refurbishment have to be considered as a whole.

2 GALICIAN HOSTELS ANALYSIS

2.1 *Climate and Location*

Galicia is a region located in the North-west of Spain. It has an Atlantic climate with mild temperatures throughout the year. The average range of temperatures is between 8ºC in winter and 20ºC in summer. With well over 1,000 mm a year this is considered the rainiest region of Spain.

The two sites where the hostels are going to be studied are Ribadiso de Abaixo and Redondela (Fig. 3). The first one is part of the French Way (main route) and it is placed in the north of Galicia. The second one, Redondela, is part of the Portuguese Way and it has less affluence of pilgrims than the one in Ribadiso de Abaixo. Although both climates follow the same trend, the dry bulb temperature in Redondela is normally around two degrees higher than in Ribadiso (Fig. 4).

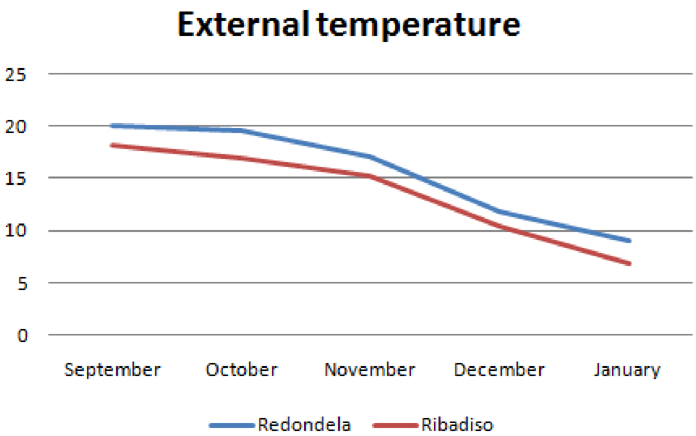

Figure 3.Location map

Figure 4.External temperatures in Redondela and Ribadiso, Spain.

2.2 *Electricity Consumption*

Monthly electricity consumption in each one of the hostels is shown in Figures 5 and 6. It shows an expectable sensitivity according to the seasons and the occupancy levels.

Pilgrim´s hostels are opened 365 a year. Both hostels have a maximum capacity of 62 occupants. Lighting and heating were unfortunately not metered separately. The heated area in Redondela´s hostel is 363.85 m². In Ribadiso the heated area is 261.28 m². Heaters in both hostels are electric and used during night time, when the electricity is cheaper.

Hostels are working normally from September to March, with slight deviations depending on the weather. They perform as expected with the highest level of consumption during the lowest temperatures. Some months experience unexpected fluctuations (e.g. November) due to the unpredictable number of pilgrims you may have each day.

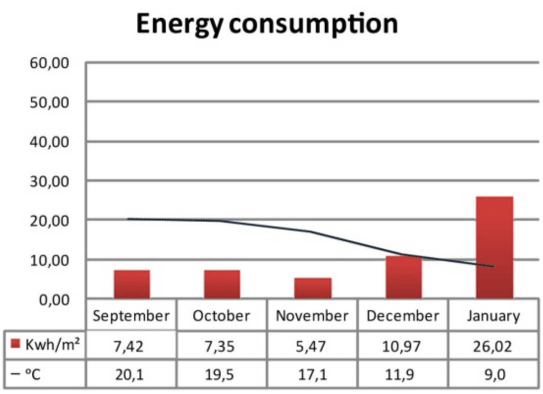

Figure 5.Sample of monthly energy consumption and external temperature of a hostel in Redondela, Spain (2009-10).

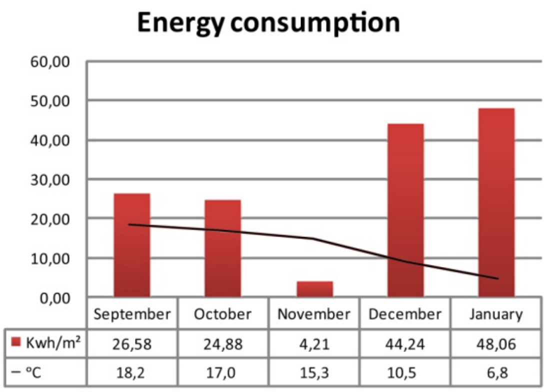

Figure 6.Sample of monthly energy consumption and external temperature of a hostel in Ribadiso, Spain (2009-10).

2.3 *CO_2 Emissions*

CO_2 emissions in accommodation receive less attention than other sectors although it accounts for the 25% of the total emissions for global tourism. There are no national or international benchmarks set up for hostels yet. Thus, they may be compared with the hotel CO_2 emissions.

They have been calculated using a conversion factor provided by IDAE of 1kWh electricity = 0.44 kg CO_2 in the final consumption.

After quantifying the CO_2 emission levels for both hostels (Fig. 7, 8) we can conclude that Ribadiso has the worst performance under a common typology and therefore it will be further analyzed.

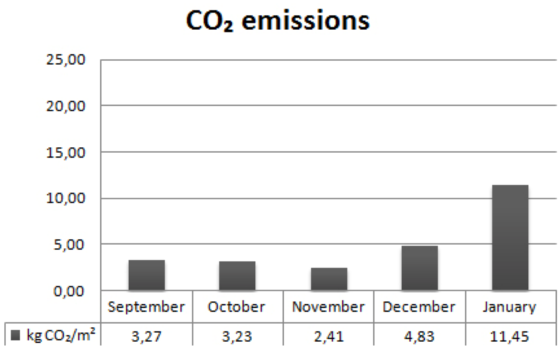

Figure 7.Sample of monthly CO_2 emissions due to electricity in a hostel in Redondela, Spain (2009-10).

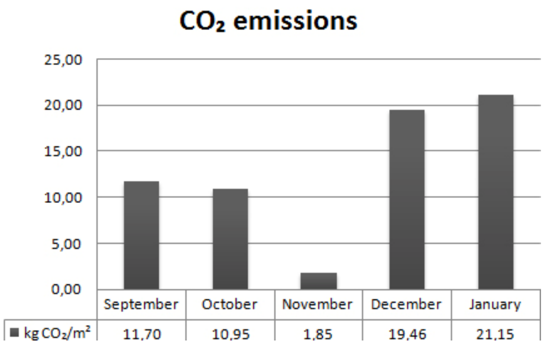

Figure 8.Sample of monthly CO_2 emissions due to electricity in a hostel en Ribadiso, Spain (2009-10).

3 RIBADISO DE ABAIXO

3.1 *Description*

“Ribadiso de Abaixo” hostel is located in the middle of the Galician countryside next to the Iso river. The original building was compound by two different volumes (583 m^2 gross area). After the refurbishment in 1992 a new one was placed in the north part of the plot, to place the restrooms (170 m²), and a wing with the rooms for handicap people (46 m^2). This last one connected with the original construction (Fig. 9). The building was during the XV siècle the hospital of the village for pilgrims and the only heating source at that moment was a chimney placed in the dining room. Nowadays, this was replaced by the use of the electrical heaters previously mentioned.

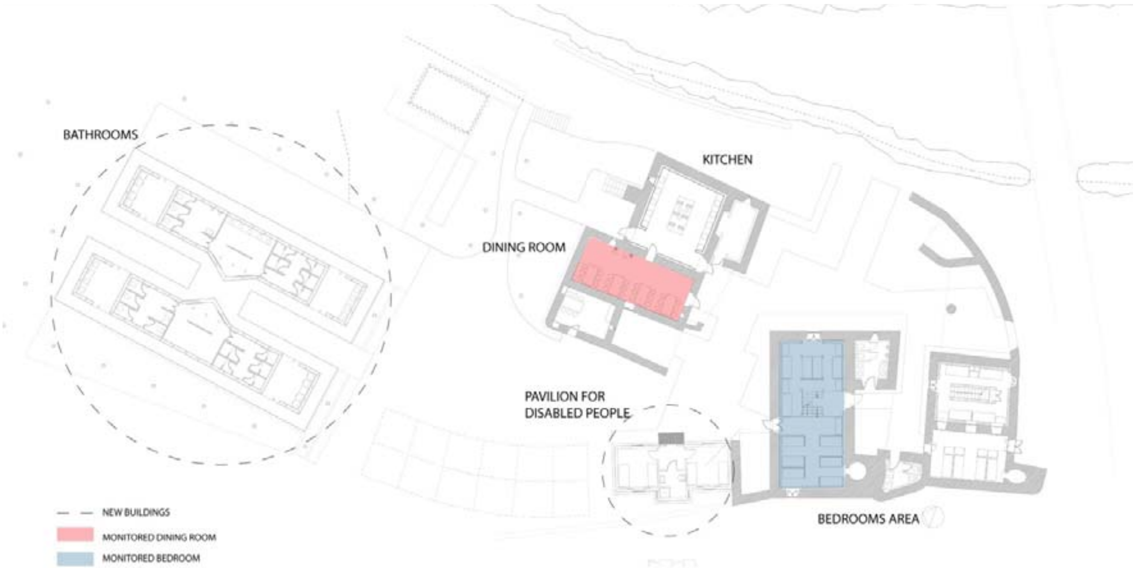

Figure 9.Ground plan of “Ribadiso de Abaixo” hostel

3.2 *Monitoring*

An average winter week was chosen to monitor the hostel (from 28/03/10 to 03/04/10). The weather station to extract the climate data is in Arzúa, 4 km away from the hostel. The occupancy levels during this week was high achieving the maximum during the 50% of the time (Fig. 10). The period of the year and the weather conditions are the two key factors that define the number of pilgrims.

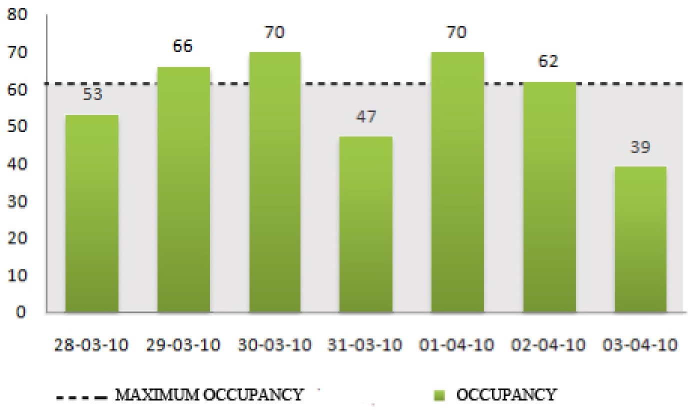

Figure 10.Ocuppancy levels of Ribadiso hostel from 28/03/10 to 03/04/10

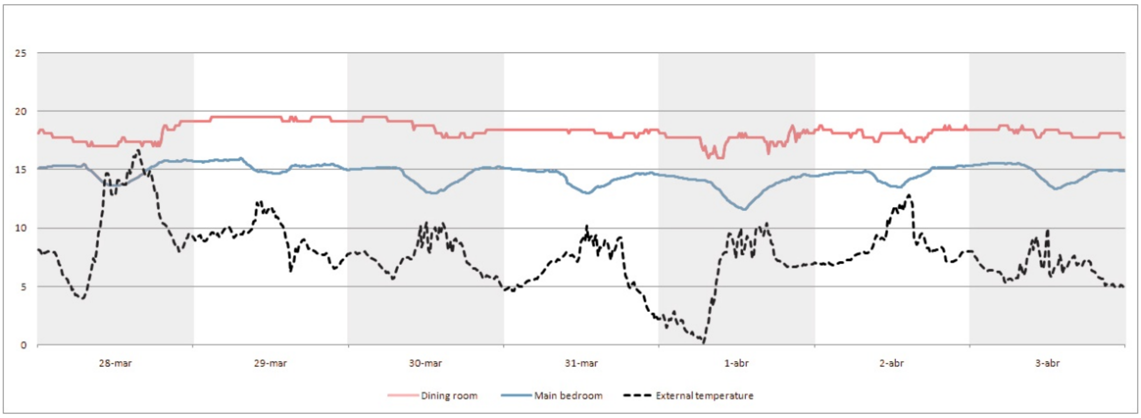

Figure 11. Monitoring of the dining and one of the bedrooms of the hostel during one week (from 28/03/10 to 03/04/10).

One datalogger was placed in each of the areas to be analyzed: the dining room (Fig. 13) and the main bedroom. Both of them are double height spaces and are built with 750 mm granite walls.

Results (Fig. 11) show that the temperatures were higher in the dining room even though the occupancy is lower than in the bedrooms. This might be due to the different proportion of heaters by m². In the dining we found four units for 38 m² while in the bedroom there are five for 71 m². It is necessary to make use of the adaptive opportunity in the bedrooms in order to achieve the comfort zone, while in the dining with external temperatures between 5°C and 10°C (Fig. 14) it is relatively easy.

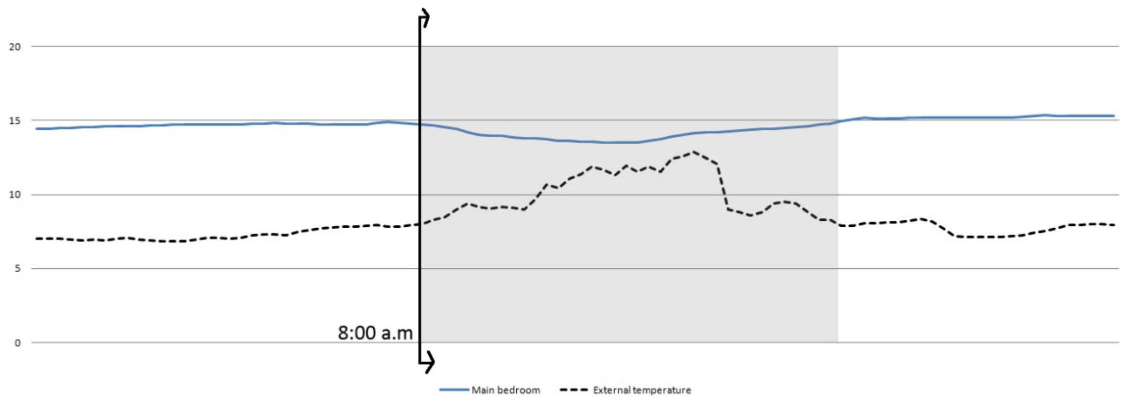

Figure 12.Monitoring of the main bedroom of the hostel (02/04/10)

The graph (Fig. 12) reflects clearly that the leaving time is at 8:00 am in the morning with a drop in the temperatures. Due to reduced number of windows and their small dimensions (window to floor ratio of 5%) the solar gains are practically null.

Figure 13.Dining room

Date	External temperature	Average temp. bedroom	Average temp. dining room
28-03-10	9,5 °C	14,7 °C	18,1 °C
29-03-10	10,0 °C	15,3 °C	19,3 °C
30-03-10	9,1 °C	14,1 °C	18,6 °C
31-03-10	7,5 °C	14,1 °C	18,1 °C
01-04-10	6,4 °C	13,1 °C	17,4 °C
02-04-10	5,8 °C	14,4 °C	18,1 °C
03-04-10	8,5 °C	14,5 °C	18,3 °C

Figure 14.Average temperatures in Ribadiso hostel

According to these results the worst performing area is the main bedroom. Further analysis was undertaken through thermal simulations on this area, trying to reduce energy consumption levels and to achieve the comfort zone.

3.3 *Analysis*

A thermal model was built up using TAS software and calibrated with data taken from the datalogger of the main bedroom. The input for the current situation is:

-Wall: Granite 750 mm covered with wood boards. U-Value 2.675 kWh/m^2

-Ground: 0.453 kWh/m^2 (No insulation)

-Roof: U-Value 0.618 kWh/m^2 (40 mm of insulation)

-Windows: Single Glazing (6mm) with a U-Value 5.731 kWh/m^2

-Frames: Teak wood frames and internal blinds

The schedules used for the simulation are:

-Lighting schedule: 18:00-23:00

-Occupancy: 19:00-20:00

-Heating schedule: 24:00-19:00

The analysis is focused on heating consumption. Cooling is not required within this climate zone. Temperatures are not extremely high during the summer period and the river and all the thermal mass of the building contributes to cool down temperatures (Fig. 15).

Figure 15.General view of the hostel next t the river.

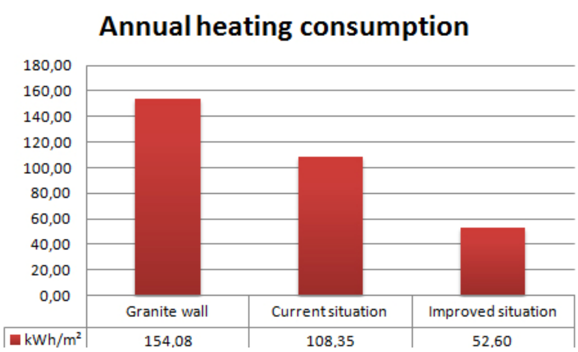

Figure 16.Annual consumption before and after the improvement of the main bedroom.

As a baseline a first analysis was undertaken with granite walls, leaving only the stone in the whole height to see how the structure of the building can perform by itself. Due to the high U-Value of the granite compared with other vernacular materials (e.g. brick) the performance is poor. Heating consumption levels compared with the current situation are almost a 50% higher (Fig. 16).

To improve the current situation some changes are applied with minor architectural implications. The main target is to optimize the final performance without compromising the original building envelope and its layout. New conditions after the improvement are:

-Wall: 750 mm of granite U-Value 2.675 kWh/m^2, covered with wood boards till mid height.

-Ground: 0.268 kWh/m^2 (50 mm insulation)

-Roof: U-Value 0.353 kWh/m^2 (80 mm of insulation)

-Windows: Low-E double glazing with a U-Value 1.81 kWh/m^2

Final annual energy consumption level after the improvement is 52.60 kWh/m^2. This means achieving the comfort zone and a reduction of 50% compared with the current situation.

To sum up, the strategies applied to the main bedroom are:

-Insulating the floor

-Insulating the wood boards for half height leaving the rest of the stone exposed to take advantage of the thermal mass

-Extra insulation in the roof

-Low-E double glazing with the preexisting teak wood frames

The remaining heating load could be reduced by changing from an electrical heating system to gas. Gas boilers have the highest overall efficiency from primary energy to useful heat. They also have the lowest CO_2 emissions and the fastest response. Further improvements may be achieved by changing the current lamps, which are mainly incandescent into low consumption. They will contribute with savings in the range of 80% (Tab. 1).

Table 1. Equivalence table between low consumption fluorescent and incandescent lamps.

Low consume fluorescent (W)	Incandescent (W)	Energy savings (%)
3	15	80
5	25	80
7	40	82
11	60	82
15	75	80
20	100	80
23	150	84

4 CONCLUSIONS AND FUTURE LINES OF INVESTIGATION

Results show a great performance and energy impact of minor design changes. The benefits identified through the analysis are as follow:

-Space heating bills can be reduced by up to 50 per cent

-Direct impact on the CO_2 emissions, reducing them to more than a half.

-Significant improvement in comfort levels

-Value of the property is increased as a result of the upgrading

Currently hostels are designed as common areas unifying people expectations in terms of comfort to only one target. A future line of investigation may be explored on how to achieve different levels of temperature within the same space. How to design the space so people can achieve different comfort zones within the same bedroom and optimize the consumption levels?

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Monitoring of Indoor Climate of a Net Zero Energy Office in Flanders

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ABSTRACT: The last decade, efforts have been undertaken to develop concepts for energy efficient buildings up to passive and even zero energy standard. However, apart from a low energy consumption these buildings should also have a good indoor climate in order to be accepted by the main public. In this context, the real performance of a zero energy office in Flanders, Belgium has been analyzed through monitoring of the indoor climate during winter/spring and summer and occupant surveys. The building was also assessed by means of 2 sustainability assessment tools. In general, the measurements showed a good indoor air quality, except for a very low relative humidity in cold periods. Weakest points were a musty smell in the morning and heat accumulation in the office during a longer hot period. The sustainability assessment showed the clear need for the personnel to be better informed on the concept of the building.

1 INTRODUCTION

The challenge of climate change and the exhaustibility of fossil fuels was the main argument for the EU to introduce the Energy Performance of Buildings Directive (EPBD) in 2002 (EPBD, 2002), which had to be implemented by the Member states by 2006 at latest. Focus of this first version of the EPBD was to avoid the construction of energy devouring buildings. The recast in 2010 (EPBD, 2010) went a step further and imposes new buildings to be nearly zero energy by the end of 2020. However, some companies do not wait for this tightening, but choose to build their office according to passive or zero energy standard right now. These companies are often related to the building sector or the (renewable) energy sector and use their office as a ‘business card’ or demonstration project towards their clients. They combine several technologies, such as thorough insulation, high levels of air tightness, mechanical ventilation with heat recovery and/or night ventilation, daylight controlled lighting, automated solar shading, heat pumps, solar collectors and/or solar panels,… to reduce the energy consumption.

However, a low energy consumption should not be the only goal. A low energy building without a good indoor climate is a badly performing and unsustainable building, that risks to create resistance against this type of buildings among the building users instead of convincing them to adopt these technologies at home. Furthermore, as these buildings still are not common practice and can be considered more or less as prototypes, a good knowledge and understanding of the in situ performance can help to improve the future to build offices of this kind.

In this context the real performance of a zero energy office in Flanders, Belgium, has been analyzed by means of monitoring the indoor temperature, CO_2 concentrations and relative humidity during winter/spring and summer and by means of occupants surveys on their perception of the building and its indoor climate. Furthermore, the building was also assessed with two sustainability assessment tools: the Dutch version of BREEAM for offices in use (BREEAM-NL BBG) as well as the Flemish tool ‘Assessment of office buildings’ (AOB), developed by the Flemish government. The scores on quality of life and wellbeing from these assessment tools were used as an additional point of comparison in the assessment of the indoor climate performance.

Section 2 will present the office building and describe the concept that has been adopted to create a zero energy building. In section 3 the methodology for the evaluation of thermal comfort and indoor air quality will be presented as well as the methodology of the assessment tools to evaluate quality of life and wellbeing. Then, section 4 and 5 will present and discuss the main results. Finally, in section 6, conclusions are formulated.

2 CONCEPT OF THE BUILDING

The building is situated in the province of Limburg, on a former mine site that has been redeveloped by the province of Limburg into a demonstration site for sustainable construction. The building is the office building of a company, active in energy efficient HVAC systems and solar energy systems. Therefore, they wanted their office to be a demonstration of energy efficient technologies, with good indoor comfort during winter and summer and with minimized heating and cooling costs. In order to increase the level of sustainability, they chose to build on this brownfield and to adopt an existing concrete skeleton that was left unfinished by another company. The building has a square ground floor and is 3 storeys high with an unheated/uncooled atrium over 2 storeys. Originally the building was conceived as a passive office building, but later on turned into a zero energy building through the installation of a large number of solar panels on both the roof and the façade. The concrete skeleton is covered with façades in wood frame construction, as can be seen in figure 1.

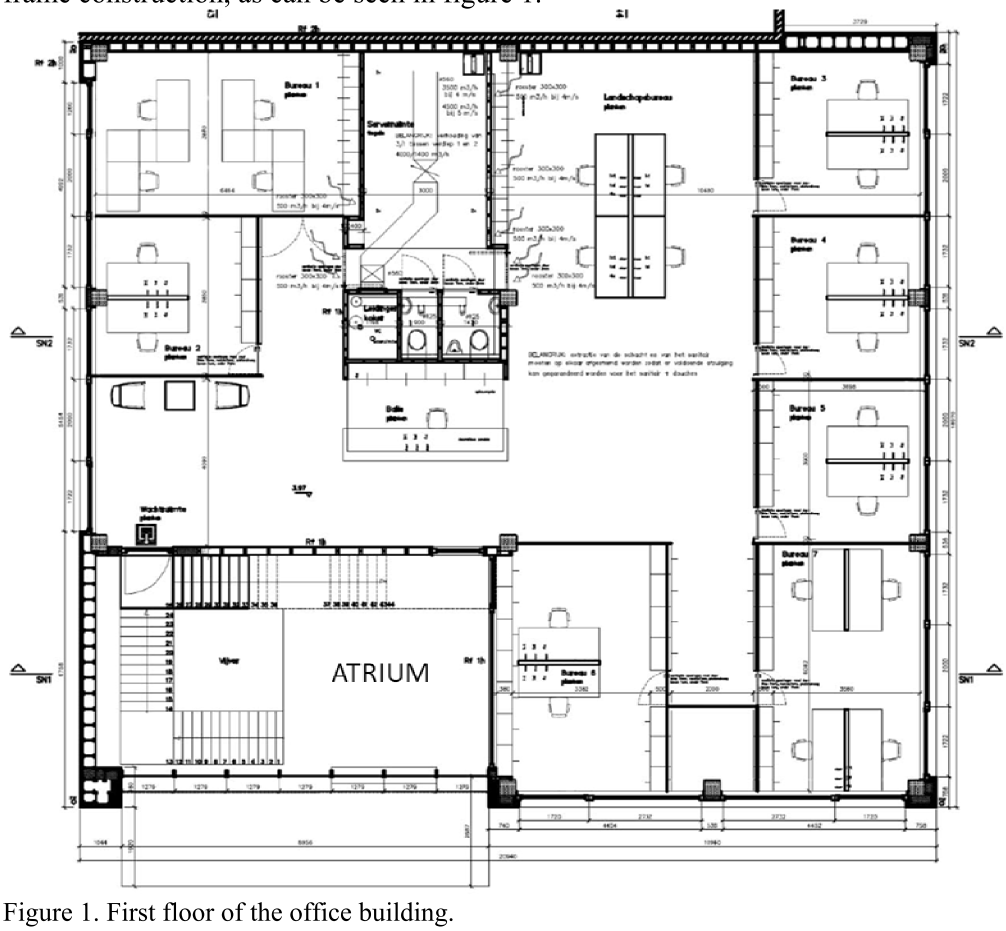

Figure 1. First floor of the office building.

The ground floor contains a storage room, whereas office spaces are located on the first and second floor. The small offices are for the employees who stay in the office, whereas an open-plan office on the second floor is used by the employees who often are on the road. Furthermore the second floor consists of a meeting room and a refectory. A maximum of 40 employees are present simultaneously in the building. Table 1 presents the main characteristics of the building and the adopted technologies. Some of these are not installed yet.

Table 1. Characteristics of the building and adopted technologies.

	In use	Not installed yet
Building volume (m³)	2500	
Heat loss area (m²)	843	
Floor area (m²)	606	
Glazing area (m²)	112	
Compactness (m)	2.97	
U-value roof (W/m²K)	0.13	
U-value façade (W/m²K)	0.13-0.18	
U-value floor (W/m²K)	0.20-0.31	
U-value windows (W/m²K)	0.74	
Overall mean U-value (W/m²K)	0.30	
Air tightness n50 (h^{-1})	0.54	
Mechanical ventilation with heat recovery and soil heat exchanger	X	
CO_2 and temperature sensor on ventilation		X
Heating- and cooling battery on ventilation system		X
Soil-water heat pump	12,9kW/COP=4.4	
Night ventilation	Manually controlled	Automatic control
Rain sensor for night ventilation control		X
Temperature sensor for night ventilation control		X
Solar shading	Manually controlled	Automatic control
Vacuum solar collector	8.25m²	
Solar panels on façade	5,76kWpeak	
Solar panels on roof	243,57kWpeak	
Rain water use	X	
Motion sensor to control indoor lighting	X	
Daylight sensor to control indoor lighting		X

During the design phase, an analysis of the predicted summer comfort was made by a consultancy firm. Different scenarios for active cooling, night ventilation, ventilation rates and solar shading were tested with dynamic building simulations in order to determine the best solution for good summer comfort without high cooling costs.

In 2011, the company was the winner of the Sustainable Construction Award for the most sustainable office building in Limburg. Unfortunately, the company went bankrupt very recently due to the economic crisis and abrupt changes in the financial support mechanisms for renewable energy by the Flemish government.

3 METHODOLOGY

3.1 *Monitoring campaign*

Indoor climate was monitored from March 23rd until April 19th 2012 and from June 22nd until July 12th 2012 in three different rooms: an open-plan office, a small office and the refectory. They are all south oriented and thus most sensitive to overheating. The indoor temperature and relative humidity were measured every 10 minutes with an ONSET HOBO U12 logger. The CO_2 concentrations were measured every 10 minutes with a Telaire 7001. Since in summer only 1 CO_2 logger was available, the logger was relocated from one room to another after a few days.

3.2 *Evaluation criteria for indoor climate*

Thermal comfort was evaluated by the mean indoor temperature and standard deviation for the different rooms as well as by the percentage of time below, in or above comfort zone. According to ISO 7730(2005) comfort boundaries are set to 20-26°C, but the temperature can be in the 26-28°C zone for less than 5% of the time.

Indoor air quality was evaluated by means of the relative humidity and CO_2 concentration. For relative humidity, the comfort zone is 30-70%. For CO_2 concentration according to EN 13779(2007) indoor air can be qualified in four levels (IDA1 to IDA4) depending on the difference in CO_2 concentration between indoor and outdoor air. For the CO_2 concentration of the outdoor air a standard value of 350 ppm is used, resulting in IDA1 (≤ 750ppm), IDA2 (750-950ppm), IDA3 (950-1350ppm) and IDA4 (> 1350ppm). For a good indoor air quality, IDA1 or IDA2 should be aimed for.

3.3 *Survey of the employees*

Apart from the monitoring, also 16 employees were surveyed on their perception and satisfaction with the indoor climate. The survey was taken on August 29th and September 13th 2012. Questions were asked on their knowledge of the building concept and on their perception of physical aspects of the office environment (interior finishing and visual view), the indoor climate (draught, temperature, air quality, light), health complaints at work and the degree of personal control on the indoor climate. They were also asked to give an overall score to the building.

3.4 *Sustainability assessment tools*

In the frame of another part of this research, two sustainability assessment tools were applied to this building in order to assess the overall sustainability level of this building as well as to compare both tools. More details can be found in (Meex, 2013; Meex & Verbeeck, 2013). As a point of comparison for the monitoring results and the survey, the scores for quality of life and wellbeing are presented here as well.

In BREEAM-NL BBG, quality of life and wellbeing is assessed through 30 questions on health aspects (percentage of glazing, daylight factors, view, measures against glare, ventilation rates, temperature control, acoustics, indoor air quality, reduction of VOC's, cleaning policy, polls on user satisfaction, promotion of drinking water,…). In the Flemish tool AOB, this is assessed by means of 31 questions on accessibility, thermal comfort, acoustical comfort, visual comfort and indoor air quality. Largest difference between BREEAM and AOB is the fact that in AOB the assessment is only focused on the performance of the building as such and executed mainly through measurements, whereas BREEAM makes a distinction between the asset, the management of the building and the use of the building by the employees. This way, not only the building as such, but also aspects of information dissemination and sensitization towards users and satisfaction of the users are assessed.

4 RESULTS

4.1 *Results on the indoor climate*

In the first monitoring period (March-April), the overall mean outdoor temperature was 9.5°C with a standard deviation of 4.2°C, a minimum temperature of -1.7°C and a maximum of 20.6°C. The mean relative humidity (RH) was 65,6% with a standard deviation of 19%, a minimum of 23,7% and a maximum op 99,9%. Table 2 gives the percentages of time a certain indoor air quality level was achieved in these rooms. Table 3 presents the mean temperature and standard deviation, the mean and minimum relative humidity and the percentages of time the temperature and the relative humidity were below, in or above the comfort zone in the different rooms. For the open-plan office, the small office and the outdoor, only working hours are considered, whereas for the refectory, only the lunch break is considered.

Table 2. Percentages of time the indoor air quality is within a certain IDA-class during the first monitoring period (March-April).

IDA-class	Open-plan office	Small office	Refectory
	Working hours	Working hours	Lunch time
IDA1	79.3%	69.3%	98.3%
IDA2	18.0%	26.7%	1.7%
IDA3	2.6%	4.0%	0%
IDA4	0%	0%	0%

Table 3. Mean temperature and standard deviation, mean and minimum relative humidity and percentages of time temperature and relative humidity are below, in or above comfort zone during the first monitoring period (March-April).

Temperature	Open-plan office	Small office	Refectory	Outside
	Working hours	Working hours	Lunch time	Working hours
Mean temperature	23.3°C	23.7°C	23.7°C	9.7°C
Standard deviation	0.9°C	0.7°C	1.6°C	4.2°C
θ < 20°C	0%	0%	5.3%	99.4%
20°C ≤ θ < 26°C	100%	100%	94.7%	0.6%
26°C ≤ θ < 28°C	0%	0%	0%	0%
θ ≥ 28°C	0%	0%	0%	0%
Relative humidity				
Mean RH	32.9%	31.7%	31.5%	65.6%
Minimum RH	22.7%	22.6%	21.2%	23.7%
RH < 30%	25.3%	27.7%	49.1%	3.1%
30% ≤ RH < 70%	74.7%	72.3%	50.9%	53.5%
RH ≥ 70%	0%	0%	0%	43.4%

In the second monitoring period (June-July), the overall mean outdoor temperature was 19.5°C with a standard deviation of 5.1°C, a minimum temperature of 8.9°C and a maximum of 32.1°C. Table 4 presents the mean temperature and standard deviation, the mean and minimum relative humidity and the percentages of time the temperature and the relative humidity are below, in or above the comfort zone in the different rooms, whereas table 5 gives the percentages of time a certain level of indoor air quality is achieved in these rooms.

Table 4. Mean temperature and standard deviation, mean and minimum relative humidity and percentages of time temperature and relative humidity are below, in or above comfort zone during the second monitoring period (June-July).

Temperature	Open-plan office	Small office	Refectory	Outside
	Working hours	Working hours	Lunch time	Working hours
Mean temperature	24.3°C	24.4°C	24.2°C	22.6°C
Standard deviation	0.9°C	0.9°C	0.9°C	4.3°C
θ < 20°C	0%	0%	0%	26.4%
20°C ≤ θ < 26°C	97.3%	98.7%	92.9%	51.2%
26°C ≤ θ < 28°C	2.7%	1.3%	7.1%	7.0%
θ ≥ 28°C	0%	0%	0%	15.4%
Relative humidity				
Mean RH	52.0%	52.5%	52%	59%
Minimum RH	37.1%	39.7%	41.3%	33.1%
RH < 30%	0%	0%	0%	0%
30% ≤ RH < 70%	100%	100%	100%	73.8%
RH ≥ 70%	0%	0%	0%	26.2%

Table 5. Percentages of time the indoor air quality is within a certain IDA-class during the first monitoring period (June-July).

IDA-class	Open-plan office	Small office	Refectory
	Working hours	Working hours	Lunch time
IDA1	71.6%	44.8%	80%
IDA2	28.4%	47.8%	20%
IDA3	0%	7.4%	0%
IDA4	0%	0%	0%

4.2 *Results of the survey*

Among the 16 surveyed employees, there were 9 men and 7 women. Of these employees, 4 had a central office with no direct window, 3 had a south-oriented office, 1 a north oriented and 1 a north-east oriented office and 7 had a north oriented office. All had a view to the outside, but for the centralized offices, the window was at more than 5 meter from the office desk. This explains why 3 of the employees in these central offices were not satisfied with the view. Only 5 said to be in the know of the principles of proper use of a passive building, whereas 7 were not and 4 only to a limited extent.

Regarding the perception of the indoor climate, table 6 gives the distribution of the answers.

Table 6. Percentages of surveyed employees agreeing on a certain quote.

Indoor climate	Not within last 4 weeks	1 to 3 days in last 4 weeks	5 to 15 days in last 4 weeks	Almost every day
Too much draught	94%	6%	0%	0%
Too little air movement	56%	13%	19%	13%
Too high temperatures	25%	31%	44%	0%
Too low temperatures	100%	0%	0%	0%
Strongly fluctuating temperatures	94%	0%	0%	6%
Air too humid	94%	6%	0%	0%
Air too dry	94%	6%	0%	0%
Musty smell	56%	19%	13%	13%
Smell of smoke, chemical products,…	100%	0%	0%	0%
Too much daylight	87%	13%	0%	0%
Too little daylight	88%	0%	6%	6%
Too much artificial light	81%	0%	13%	6%
Too little artificial light	100%	0%	0%	0%

Apart from these answers, 5 employees complained about glare on the computer screen due to sun/daylight, 11 complained about too high temperature in summer, especially at outdoor temperatures above 25°C and 2 complained about too low temperature in winter. There were no complaints about noise nuisance from outside or bad acoustics in the office. Only the noise of the HVAC system was mentioned as disturbing by 3 employees.

With regard to work related health complaints, the complaints were rather limited: 4 employees (wearing contact lenses) had experienced dry, irritated eyes in the last 4 weeks, 5 suffered from sneezing and 5 complained about stiffness in the back, shoulders or neck.

Regarding the personal control on the indoor climate, all answered to have no control on temperature or ventilation, as there is no thermostat or control system available. The only way of personally controlling the indoor climate is by opening/closing windows, opening/shutting down the solar shading and switching on/off the artificial lighting.

The mean overall score on the building by the employees was 7.3/10. Further remarks were: a musty smell in the morning, often too warm and ventilation openings too distant from the office desk, need for more ventilation and cooling during summer and too few windows that can be opened.

4.3 *Scores on quality of life and wellbeing in the sustainability assessment tools*

Table 7 gives a summary of the aggregated scores for the health aspects of BREEAM –NL BBG. Distinction is made between the asset, the management and the use of the building.

Table 7. Scores for the health aspects in BREEAM-NL-BBG.

	Asset	Management	Use
Day lighting and artificial lighting	17/20	4/4	0/0
Acoustics	0/0	4/4	0/0
Ventilation and air quality	13/14	2/8	0/0
Indoor temperature and temperature control	12/16	0/0	0/0
Prevention of pollution	4/8	6/17	0/0
Interaction with the building users	1/1	4/8	9/30
Total score for health aspects	78%	49%	30%

In the overall BREEAM score, the score for health aspects has a weighting factor of 21% for the asset, 15% for management and 15% for use of the building. Table 8 gives a summary of the aggregated scores for the quality of life and wellbeing of the Flemish AOB. Here, only the building is assessed, not the management nor use of the building.

Table 8. Scores for quality of life and wellbeing in AOB.

	Building
Accessibility	0/4
Thermal comfort	2.6/4
Visual comfort	2.4/4
Ventilation and air quality	3.3/4
Acoustical comfort (could not be assessed due to lack of appropriate monitoring equipment)	-
Vibration comfort (idem)	-
Total score for quality of life and wellbeing	2.1/4

5 DISCUSSION

As both the measurements and the surveys show, the thermal comfort in winter/ spring in the offices is good with a mean temperature of 23°C and 100% of the time within comfort boundaries. The relative humidity however is too low, since more than 25% of the time the relative humidity is below 30%. This is due to the fact that the HVAC system does not contain a humidifier. The indoor air quality in winter/spring is good, with only 3-4% of the time in IDA3 class, thus a CO_2 concentration between 950-1350ppm. The rest of the time the concentration is below 950ppm, even at least 70% of the time below 750ppm. This means that through the combination of a good air tightness and a well designed balanced ventilation system, a good air quality can be guaranteed here. However, the surveys revealed a problem of musty smell, especially in the morning. This could be explained by the fact that there might be a problem of mould or bacterial growth in the ground pipes or filters. Since the ventilation system is turned off during night, there might be an accumulation of mould particles during night, which are released in the morning when the ventilation starts up. Therefore extra quality controls of the ventilation system are needed in the future.

In summer, the indoor temperature is mainly acceptable with a mean temperature of 24°C and less than 3% of the time a temperature between 26°C and 28°C in the offices. However, a more detailed analysis of the temperatures shows that there is an accumulation of heat within the building in a period of successive warm days outside. This can be seen in figure 2 which gives the indoor and outdoor temperature during the warmest week of the monitoring period.

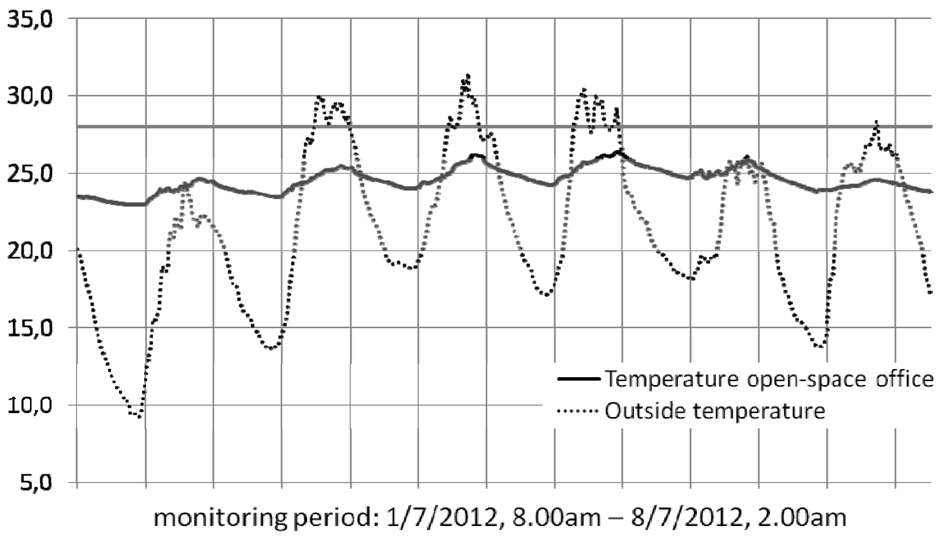

Figure 2. Indoor and outdoor temperature during warmest week in summer.

From these results it can be concluded that neither the cooling capacity of the night ventilation nor the precooling effect of the ground pipes is sufficient to keep the building within comfort zone during a longer warm period. Once the building is heated up, there are little measures left to improve the thermal comfort. This also appeared from the surveys, as 75% complained about too high temperatures within the 4 weeks before the survey and 44% complained about too little air movement (logical as higher air velocities also can improve the thermal comfort during warm periods). Recent summers in Flanders did not contain long periods of high temperatures, but normally summers in Flanders can have some weeks of outside temperatures above 25°C, so in the future this might lead to larger problems of overheating. The installation of a cooling battery on the ventilation system is planned and will be necessary to avoid future overheating.

The quality of life and wellbeing assessment within the sustainability assessment tools confirmed the results of the monitoring and surveys, namely that the thermal comfort and indoor air quality are quite well, despite the remarks above. However, especially the BREEAM assessment also revealed that the interactions of the building manager with the users are very limited. These interactions relate to satisfaction polls among the building users, information sessions or sensitization actions on how to use the building properly, initiatives to improve the wellbeing of the personnel and managerial target figures and action and improvement plans on this theme, which are not present in the company. This was also confirmed by the surveys, as only 5 of the surveyed persons were in the know of the principles of the building and 4 only to a limited extent. Upon inquiry with the managers, it appeared that information on how to use the solar shading or how to deal with the night ventilation was only passed to the employees in adhoc situations when problems or misuse occurred. There was no systematic information transfer to (new) employees.

6 CONCLUSIONS

The in-depth analysis of the indoor comfort in this zero energy office building showed a (rather) good performance on thermal comfort, indoor air quality, visual and acoustical comfort both in winter/spring and summer. However, as in many low energy buildings that have no active cooling, also here it appeared that it is not evident to avoid heat accumulation in the building during a longer hot period. Night ventilation and ground pipes have a positive effect, but their cooling capacity is not sufficient to keep the indoor temperatures within comfort zone during a hot period. This is certainly partly due to the fact that most of the automatic control systems are not operational yet and therefore control of the indoor temperature depends on the proper use of windows and solar shading by the building users. However, most employees are not informed well on the principles and functioning of a passive office building. It then can be concluded that a well thought concept of a passive/zero energy building is a first and important step, but evenly important is the sensitization and information of the building users afterwards in order to maximize the energy saving potential of and comfort in the building.

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The qualifications and professional competencies of architects on the energy efficiency of buildings. Are they prepared to embrace the 2020 targets ?

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ABSTRACT: The recast Energy Performance of Buildings Directive requires that from 2020 onwards, all new buildings are nearly zero-energy buildings. This new concept requires a strong implementation of sustainable construction methods and techniques as well as the integration of renewable energy technologies in building architecture. Among the stakeholders, architects intervene at an early stage of any building construction process. A survey and expert interviews were conducted, and a review of literature was carried out, followed by a comparative analysis of the structures and degree syllabuses of Portuguese architecture degree courses. The most common problems reported were the lack of dissemination of the EPBD requirements and the need to improve access to regulations, tools and methods, as well as best practices. The conclusion drawn from these results is that it is essential to raise architects awareness towards the important role that they can play in the implementation of these new requirements.

1 INTRODUTION

The new concept of buildings for the future involves a range of building materials and systems that place major emphasis on the issue of sustainability and energy efficiency. This requires for a deeper approach to these issues in order to help professionals to focus on the implementation of real solutions for the buildings.

Bearing in mind that an integrated design process has become the norm and that energy efficiency has become one of the priorities of a building project, design project teams must start looking at energy and performance issues early on and throughout the whole design and operation process. Architects belong to the group of professionals who will most likely make up the first design concept together with the client and other investors and consultants. As a building is designed, all the aspects of sustainability, bioclimatic solutions and buildings physics can be considered from the initial step, which will help engineers to achieve higher levels of optimization of the building energy performance. Additionally, the recast Energy Performance of Buildings Directive - EPBD - (European Parliament and Council of the EU 2010) requires that from 2020 onwards, all new buildings are nearly zero-energy buildings and, therefore, architects need to acquire, in a short/medium term, the sufficient knowledge to deal with these recent requirements. Thus, it is important to analyze whether sustainability and energy efficiency has been sufficiently discussed through the architecture degree courses and how prepared these professionals currently are, as well as how they are putting these subjects into practice in their design projects. The architects' role is undoubtedly important in the initial design phase of a building because they are the main responsible for defining many of the sustainable construction methods and techniques.

2 SCOPE AND METHODOLOGY

The focus of this paper is to give an evidence-based image of how deeply the subjects related to sustainability, energy efficiency and bioclimatic solutions are being learned by architecture degree courses undergraduates as well as of how these subjects are being put into practice in the design projects. As well as this, it reports on the barriers architects feel that they are facing nowadays and on their expectations about these matters for the near future.

In order to reach the aim of this study, a literature review was carried out, followed by a comparative analysis of different structures and degree syllabuses of architecture degree courses in Portugal. The analysis focused on the scientific areas and degree syllabuses of the course units in order to find out to what extent the subjects are part of the undergraduate learning outcomes. The statutes and regulations of Professional Orders and other Associations were also reviewed so as to understand the actual requirements and framework related to professional qualifications. In addition to this, a survey and expert interviews to architects were conducted. Based on the questionnaire structure and feedback, some additional interviews were held.

The inquiry and the interviews involved a total of 40 architects. The respondents work mainly in design project in Northern Portugal and their ages range from 26 to 55 years old. About 22 of the respondents have a Master’s degree, 17 have a license degree and one has a license degree and a post-graduation. They all obtained their qualifications between 1986 and 2012, respectively. The majority of the respondents (70%) attended private higher education institutions and the other 30% attended state higher education institutions. About 50 architects were invited to answer the questionnaire, from recent graduate architects to more professional experienced architects.

The inquiry consisted of 30 questions, the majority being close answer questions. Some of the respondents recorded their answers directly on the questionnaire form whereas others were interviewed, in which cases the respondent followed the questionnaire as well as the normal procedures recommended for these cases by Yin (2002).

3 GOALS AND CHALLENGES OF THE RECAST EPBD

According to INE (2011), energy consumption in buildings in Portugal represents about 30% of the total consumption (17.7% in the domestic sector and 12% in services). Furthermore, the energies used in buildings tend to be depleted, and Portugal, as well as the other European Union countries, greatly depend on energy when compared with other countries (79% of imported energy in 2011) (Conselho de Ministros 2013).

As far as climate change and energy are concerned, the European Parliament proposed a plan of action, the “Climate and Energy Package: Triple 20’ targets until 2020”, whose goals are as follows: a 20% reduction in greenhouse gas emissions from 1990 levels; raising the share of energy consumption produced from renewable sources to 20% and a 20% improvement in energy efficiency until 2020.

According to Commission of the European Communities (2008) energy efficiency represents one of the goals of the climate and energy package, being one of the main means to reduce C02. The buildings sector represents one of the fields of action. The directive 2010/31/EU, of May 19 2010 (Energy Performance of Building Directive - EPBD) recast the directive 2002/91/CE, and consolidated that goal.

The biggest novelty about the recast EBPD (European Parliament and Council of the EU 2010) is that it makes it mandatory for buildings to be nearly zero-energy buildings after 2021 (NZEB “Nearly Zero Emissions Building”). Besides this, it also points towards the importance that retrofitting existing buildings assumes as an opportunity to take sustainable measures and improve their energy performance. Energy certification remains mandatory and the demands concerning energy efficiency will tend to increase. According to EPBD, a building with nearly zero energy needs is a building with a very high energy performance. The nearly zero or very low energy needs must be covered by energy from renewable sources produced locally or nearby. According to Aelenei (2012), the main issue is the annual energy balance between consumption needs and production.

The International Energy Agency (IEA 2013) and through the Solar Heating & Cooling Programme, Task 40 and ECBCS Annex 52, is working on a definition of the net zero-energy buildings (nZEB) in order for the various member states to standardize the main guidelines to be followed based on experimental projects which relate different countries' realities as far as construction and building use are concerned.

According to Aelenei et al. (2011), zero energy balance buildings (NZEB) can be considered as an evolution of Low Energy Consumption Buildings or Passive Houses. Passive approaches play a crucial role in addressing NZEB design as they directly affect the heating, cooling, ventilation and lighting loads put on the buildings mechanical and electrical systems, and indirectly, the strive for renewable energy generation, in Aelenei et al. (2012). Thus, the optimization of architectural design is pointed out by several experts as one of the key measures to reduce energy needs.

In a recent European study elaborated by the Architects Council of Europe (2012) about the practice of architecture, the respondents agreed that energy efficiency is a key driver in the design of buildings today. The results show that 50% "strongly agree" and 40% "slightly agree", approximately 10% disagree, among which 2% "strongly disagree". The same study assessed how architects feel towards the competence to design a NZEB (Nearly Zero Energy Building). The percentage of architects who feel "very competent" and "competent" depends on the country, but it varies from 32% in Sweden to 80% in Austria. Portuguese architects' answers reveal a percentage of 60%. The study shows that there is no improvement from 2010 until now concerning how competent architects feel to design a Nearly Zero Energy Building in Europe. On the other hand, the answers to the question about how often respondents are currently asked by clients to design with NZEB standards or through regulation showed that a little more than half of the respondents are asked less than 10% of the time, and only 13% of the respondents are asked more than 50% of the time. These and other studies lead to the conclusion that architects are relatively aware of the advantages of these matters but the implementation in buildings is still far from being a current practice.

4 THE ARCHITECTURE PROJECT DESIGN AND ARCHITECTS' QUALIFICATIONS

4.1 *The evolution of the architecture requirements and its contribution to sustainability*

The adaptation of construction to climate as well as the use of local and natural resources gave rise to vernacular architecture. The industrial revolution marked the appearance and spread of new materials and technologies, thus marking the rupture with the traditional solutions. As a result of the dazzle of technological development, together with the low cost of fossil fuels, the balance between climate, culture and local materials was disturbed. The answer consisted of applying artificial solutions which consume energy in order to meet comfort needs. The oil crisis as well as the environmental disturbances and the great energy dependency on non-renewable resources are all concerns resulting from the society's contemporary lifestyle. In Portugal, these concerns have been felt and expressed in various ways. Besides the international and European energy and environment policies which result in national directives and requirements increasingly more specific, some buildings assessment and certification methodologies have also appeared. Some of these methodologies, such as energy certification, are mandatory, but others are voluntary, such as sustainability assessment methods. Meanwhile, new concepts have been appearing and architecture has been constantly described as "Green", "Eco-friendly", "Bioclimatic", "Passive", "Sustainable", etc. Moura (2007) disagrees with these adjectives used to describe architecture, claiming that "There is no eco-friendly, intelligent or sustainable architecture. There is only good architecture." The same author refers that "*architecture does not have to be sustainable. In order to be good, architecture is implicitly sustainable.*" Unfortunately, this is not always the case, and Simon & Graham (2006) said "*debates about sustainable architecture are shaped by different social interests, based on different interpretations of the problem, and characterized by quite different pathways towards a range of sustainable futures*". Anyway, these tools and new concepts promote sustainability.

The design of a new building involves the drafting of a range of projects, namely the architecture project and partial specialties projects. Portuguese Law n. 31/2009 of July 3 describes the design project as "the coordinated set of written and drafted documents, integrating the main project and the other projects, which define and characterize the functional, aesthetic and constructive conception of a construction work (…)" The same law describes the main project as "the one which defines the features imposed by the function of the construction work and represents the matrix for the other projects which condition it and are conditioned by it." Therefore, the architecture project of a building represents the main project, which means that the other projects must respect it as a matrix.

In Portugal, the transposition of the first EPBD (European Parliament and Council of the EU 2002) gave rise to a new regulation for buildings thermal behavior – RCCTE (2006), whose application is mandatory in a new building design project, as well as it is the building energy certification. The RCCTE changed significantly the calculation methodology and introduced new requirements regarding the buildings surrounding environment as well as the mandatory installation of solar collectors. It is possible to say that the demands regarding the quality of the thermal project increased significantly with the introduction of the Buildings Energy Certification System (SCE) as a consequence of the project's validation by a qualified expert and the issuing of the respective certificate. These new requirements and demands also condition the architecture project in various respects, namely: the increase of the thermal insulation and walls thickness; the treatment of thermal bridges and the integration of solar collectors.

These were some of the novelties resulting from the current legal requirements which implied a change in the buildings architectural design. These new requirements gave rise to the development of new constructive solutions, such as: ventilated façades, prefabricated insulation systems, heat pumps, and photovoltaic systems, among others.

The recast EPBD brought about an even bigger challenge as it is necessary to implement practices which are allied to the current technology and which are sustainable throughout the building life cycle. It is important to highlight that the new national law which transposes this directive was passed by the Council of Ministers in June 2013, in which a review of the existing national law was carried out and several scattered laws were assembled into a single law.

4.2 *The architect's role in the context of sustainability and EPBD*

The recast EPBD refers that "*Member States should enable and encourage architects and planners to properly consider the optimal combination of improvements in energy efficiency, use of energy from renewable sources and use of district heating and cooling when planning, designing, building and renovating industrial or residential areas*". The recognition of the importance of the architects' role in the implementation of this directive is unanimous.

In the Directive n. 2008/C319/05 of December 13 on the Council's Conclusions regarding Architecture, it is assumed that "*architecture, a subject of cultural creation and innovation, namely technological, represents a notable illustration of what culture can give to sustainable development due to its impact on the cultural dimension of cities as well as on the economy, on the social cohesion and on the environment."*

In turn, in the 12th Congress of Architects promoted by the Portuguese Order of Architects (2009), the need for the creation and implementation of an Architecture public policy was expressed, in the light of what happens in most countries in the European Union. Such policy should imply, among other goals, the promotion of sustainable construction best practices, energy efficiency and the fight against climate change with regard to buildings, cities and landscapes. In addition to this, such policy should also value culture and citizenship, as well as architects' professional practice.

4.3 *Qualifications for the practice of architecture*

According to Portuguese Law 31/2009 of July 3, from October 31 2014 onwards, architecture design projects will be drafted and signed by architects who are members of the Order of Architects only. The duties of the design project's authors include the compliance with the norms and law in force and the application and justification of the solutions which comply with the required demands; the guaranty of aesthetic, functional and feasibility levels of the project and construction work; the guaranty of a joint work with the project's coordinator in the harmonization of the written and the designed elements in order to ensure integrity and coherence. In the construction phase, designers must provide technical assistance.

The design of a building involves the drafting of the architecture project (matrix project) by an architect or by a team of architects, as well as the drafting of specialties projects by engineers of various specialties. Ideally, this group of technicians would work in the same physical space and as a team. According to The Architects Council of Europe (2012), technicians' work is often done in an individual and isolated way, without any team spirit. However, one of the technicians involved in the project has to take the role of the project coordinator. In the construction of buildings, the architect or one of the architects in the team often takes that role. The project coordinator has to ensure the articulation among the project team with regard to the construction work features, the compatibility between the various projects and the compliance with law and regulations concerning each specialty, so that the interpretation of the project by the various stakeholders of the construction execution is unequivocal. Therefore, the project coordinator must have technical knowledge in several areas.

According to the same Law n. 31/2009 of July 3, architects can also play the role of construction manager and of "engineer". These figure must ensure the execution of the construction work and the compliance with the execution project, and the "engineer" must check the execution of the construction work. Both must ensure the compliance with law and regulations. However, in order to be able to play these roles, architects, as well as other technicians, are subject to a set of minimum requirements and exceptions related to work experience and others.

Architects assume a crucial role in the constructive process, either as designers or as coordinators, project managers, engineers or construction managers. Also, architects are usually the ones who establish communication with the project client. Therefore, they must be able to identify the client's comfort and habitability needs, and they must have the knowledge required to ensure that those needs are met, implementing optimized solutions as far as energy performance and environmental and economic sustainability are concerned, and giving priority to passive solutions.

5 COMPETENCIES ACQUIRED IN ARCHITECTURE DEGREE COURSES

According to Portuguese Law 74/2006 of March 24, the Architecture curricular training confers the Master's degree with 300 ECTS (European Credit Transfer System). The degree course is proposed by the higher education institution and is then assessed and accredited by the Portuguese Higher Education Evaluation and Accreditation Agency by Regulation n.º 504/2009 of December 18. The first 180 ECTS confer the license degree. The Order of Architects confers the title of architect to the graduates who "*are in possession of certificates stating the academic qualifications foreseen by the Application Regulation, n.1 article 2, (license degree in Architecture in a course certified before March 24 2006, or integrated master's degree in Architecture with a course syllabus certified after March 24 2006)*", or alternatively, who are in possession of a training certificate in architecture registered in the European Directive 2005/36/CE of September 7 (European Commission 2005). The candidates to the title of Architect must also attend a traineeship and are subject to mandatory training sessions as well as to passing an exam of "Knowledge Verification in Status and Deontology."

According to the research done on the structure of the Architecture degree courses taught in Portugal, the weight of the subjects related to energy efficiency and energy technologies represents between 5 and 6 ECTS among the total 300 ECTS for each cycle of studies, and such subjects can also be approached in the Project curricular units, although only as autodidactic research in most cases. In the face of the importance of the topic, the low incidence of these subjects throughout the courses seems insufficient to the adequate preparation of the future graduates. According to Byrne (2013), some areas, such as resource management and energy efficiency, have been absent from architecture degree courses and retrofitting has always been a disregarded area in architecture.

However, the market has increasingly been providing an offer of extracurricular courses and training sessions. Currently, there is an offer of courses addressing energy efficiency and sustainable construction, namely some master's degrees and post-graduations as well as more specific courses such as the Passive House Norm. Also, there are seminars, conferences, and workshops promoted by various entities. Most, if not all the training offer is held on the coastal area and at times which make it difficult for professionals from the inland area to take part. The time to implement and put the new requirements of the recast EPBD into practice is short. It is important that the architects' curricular training addresses buildings energy efficiency and renewable energies.

6 CURRENT POSISTION OF ARCHITECTS TOWARDS SUSTAINABILITY AND ENERGY EFFICIENCY

6.1 *State of knowledge, barriers and drivers*

The results of the study enable us to make some considerations on the state of knowledge, the barriers, and the drivers of architects regarding this issue. With regard to the architects' motivations and positive considerations, we highlight the ones in Table 1. With regard to the barriers felt by architects, we highlight the ones in Table 2.

Table 1: Main positive considerations and drivers

1	Working in team and in the same physical space makes decision making easier and increases the Project quality, as problems and doubts are sorted out more easily.
2	SCE brought more transparency into the information to provide to the client, increased the Project quality as well as the stakeholders' accountability.
3	There is an environmental awareness and architects are open to the adoption of sustainable solutions
4	Professionals are already adopting strategies such as: solar exposal of façades and insulated fenestration; shading; natural lighting; insulation equipment incorporation; and thermal bridges treatment.

Table 2 – Main barriers

1	Law regarding the buildings energy certification system (SCE) is considered quite specific and bureaucratic, thus difficult to implement, especially in retrofitting cases. (The law in force demanded changes in the construction habits, namely: the integration of solar collectors; the increase of insulation thickness; the increase in number and quality of constructive details; and the increase of the project drafting time.)
2	SCE increased the costs to the client.
3	Architects consider the adoption of some sustainable and passive solutions and technologies difficult to put into practice, especially due to: lack of knowledge, even regarding energy benefits; lack of the client's awareness; low expression in the market; and increase of costs.
4	There is still a very low implementation in buildings of passive bioclimatic strategies, such as: Trombe walls; annex greenhouse; green roofs and walls; evaporative cooling;
5	The idea prevails that the implementation of active solutions such as acclimatization systems, hot water preparation, and renewable energy incorporation leads easily to the energy class increase and, therefore, the implementation of other passive solutions is neglected.
6	Some architects consider there is still a lack of expert engineers to support architects in the design of these building sustainable solutions.
7	There is the perception that the Portuguese Order of Architects does not provide an accessible and sufficient promotion of knowledge updating.

With regard to the knowledge concerning bioclimatic/low energy consumption projects/solutions, 62.5% of the respondents find it insufficient. In turn, most of the knowledge they have was acquired through training sessions and self-initiative research. About 36 of the 40 respondents intend to attend courses in this area in a short time. Some specialists believe that training for engineers and architects in this area should be differentiated and that architects should be informed and advised about the best solutions by specialized engineers.

Over 60% of the respondents have knowledge regarding passive/bioclimatic strategies such as: Trombe walls; green roofs; geothermal acclimatization; annex greenhouse and evaporative cooling.

Little more than half of the respondents take the design project economic feasibility into account when adopting passive strategies. However, only 37.5% of the respondents get clients' feedback on economic savings and comfort levels through the solutions adopted.

About 75% of the respondents do not take the law in force into account in the architectural design of low energy consumption buildings. As well as this, 87.5% of the sample does not have knowledge regarding 2010 EPBD. Also, 70% do not have knowledge of the requirements after 2020 regarding nearly zero-energy consumption buildings (NZEB), or consider the regulation on energy efficiency well-adapted to the building retrofitting specificities.

In general terms, the implementation of an architecture policy is inexistent, and so are methodologies which favor the implementation of bioclimatic solutions and the quantification of their economic and environmental benefits. The inexistence of practical examples adapted to the different regions of the country is also transversal and causes contempt towards the principles which support the solutions implemented in vernacular architecture, which is also visible as far as the law in force is concerned. This contributes to the conditioning of wider retrofitting practices.

6.2 *Recommendations and improvement actions*

Based on the results of this study, it is possible to put forward some recommendations and improvement actions, presented as follows:

- The existence of an architecture policy focused on sustainable development and energy efficiency, with a more practical implementation feasibility and containing examples;
- The adaptation of the learning outcomes and syllabuses of the architecture degree courses curricular units, placing emphasis on subjects regarding sustainable building, energy efficiency, renewable energy systems and energy retrofitting.
- The promotion of courses/training sessions focusing on NZEB, bioclimatic solutions, energy efficiency, renewable energy and sustainable construction;
- A higher focus of the law in force on building retrofitting;
- The provision of technical Thematic Guides/Catalogues containing successful building practices and examples adapted to each region, among other elements;
- A higher level of freedom of action regarding building retrofitting;
- The promotion of research on methodologies adequate to the incorporation of various bioclimatic solutions and mechanisms to accelerate their integration process in the SCE. Town Councils can promote their implementation by reducing the Property Taxes on NZEB.

7 DISCUSSION AND CONCLUSION

The aim of this study was to understand the level of preparation and knowledge that Portuguese architecture experts have regarding sustainability and energy efficiency issues.

The new directive brings about more changes regarding construction requirements and methods. The conclusion drawn from the study was that architects play a crucial role as decision-makers, coordinators and communicators with the client, since not only do they integrate the project from the very beginning, but they are also given the qualification to perform these tasks. However, the study shows that most of the architects inquired recognize that their degree course did not provide them with sufficient skills or tools to implement sustainable and bioclimatic solutions in buildings. As well as this, the degree course syllabuses register a low number of ECTS, and consequently few learning outcomes concerning these issues throughout the learning process.

The respondents generally agree that the SCE contributes to improve the project and the construction work quality as well as the stakeholders' accountability. However, it also requires for a higher level of knowledge concerning the implementation of constructive and system solutions. Thus, team work improves the quality of the work, but is hardly put into practice. The results also show that the respondents consider that legislation, bureaucracy and costs related to SCE influence many of the technical options, especially as far as older buildings retrofitting is concerned. Many architects have been demanding more training and more tools for decision support, as well as further clarification of the regulations. Thus, it is necessary to develop and publish clear and specific information on the implementation of practical examples of passive and energy efficiency solutions adapted to each region.

In conclusion, the achievement of NZEB in the end of 2020 attending sustainability does not appear to be an easy process, as it requires the effort and cooperation of various stakeholders as well as the mobilization of various resources. Furthermore, it seems clear that there is still some way to go towards raising the architecture professionals' awareness of the important role they play in this domain. Thus, it is necessary to accelerate the creation of mechanisms which help them feel and actually be better prepared to embrace the challenges set by the new regulation and the goals for 2020.

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Chapter 2

Policies for Sustainable Construction

Including sustainability into portfolio decisions: The example of the University of Vienna

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ABSTRACT: In certain cases it is inappropriate to examine a real estate portfolio just from a mere economical point of view. Using the example of the University of Vienna a holistic assessment system is presented, that, contrary to the classic portfolio management approach, considers also sociocultural criteria. Thus, it is possible to make sustainable and at the same time objective decisions.

1 INITIAL SITUATION

The real estate portfolio of the University of Vienna is quite heterogeneous: 81 objects with about 495,000 square metres gross floor area are distributed over 75 places in the city (cp. fig. 1). In addition to its scattered facilities the portfolio contains objects for which no official consensus exists on their accessibility, fire protection and employees` safety. This is coupled with an in parts considerable holdup in maintenance and the very variable ownership structure of the buildings used by the University.

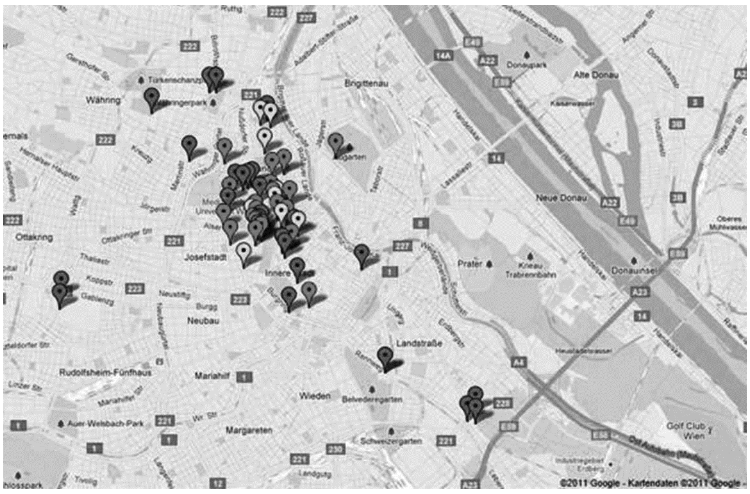

Figure 1. The distribution of the University of Vienna`s facilities.

For these reasons the University`s aim is to reduce the number of locations to four centres. Furthermore, besides a cost-reduction, the efficiency of space should be raised and the buildings` quality and functionality enhanced. To this end a portfolio management system was to be established. However, it soon became clear, that the classic system, considering the three axes ”object quality“, ”quality of location“ and ”rental success“, would not fulfil the University`s requirements. Being an institution of the public sector, it cannot take mere economic decisions, especially as its offered goods, research and education, cannot be managerially optimised. Moreover, the University`s various stake-holders` demands – from students to professors and the state as its proprietor – are highly diverging.

For institutions like the University of Vienna it is thus indispensable to consider, besides the economic criteria, ecological and sociocultural criteria as well, when it comes to portfolio management. As a result a new and sustainable approach had to be developed.

2 THE INSTALLATION OF A SUSTAINABLE PORTFOLIO MANAGEMENT SYSTEM

2.1 *Selection and weighting of criteria*

Initially suitable criteria for the assessment of buildings had to be found. Taking into consideration the University`s business strategy and the German DGNB sustainability system, 39 criteria for the objects` quality were decided upon (cp. fig. 2). These can be divided into organisational, technical and economic criteria, according to the three columns of sustainability. In doing so, the criteria for socioculture and ecology – for example comfort in summer and winter – are included in the organisational criteria.

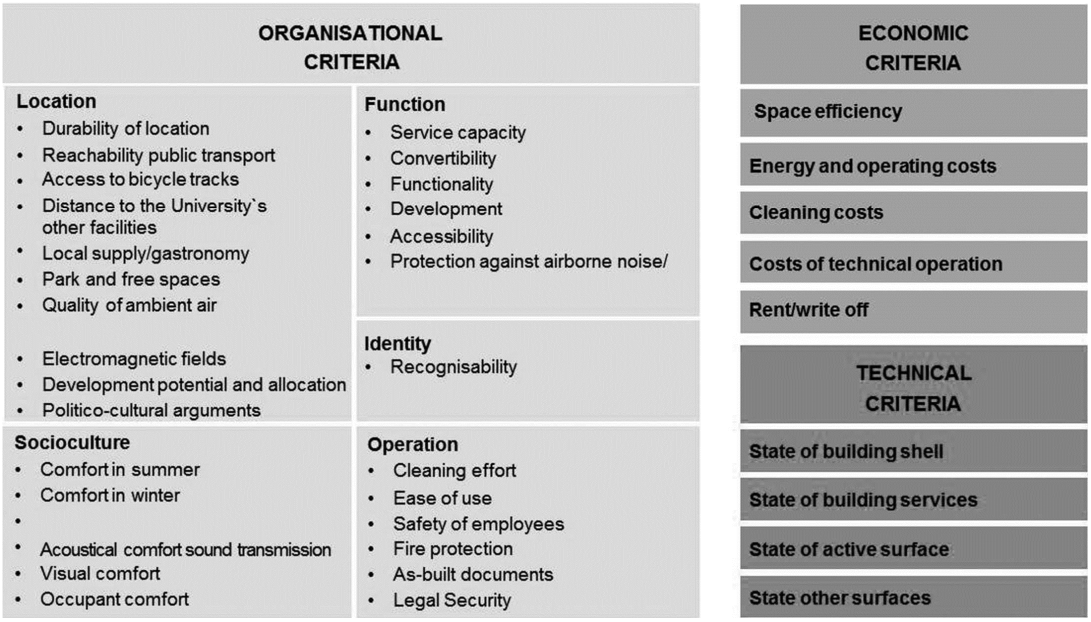

Figure 2. The assessment criteria of the University of Vienna.

Then the individual assessment criteria had to be weighted. Here the rather diverse interests of the different users had to be considered. On a scale from one to ten, students, for example, prioritise the access to a bicycle track with the top score of ten. The University`s rectorate, however, rates this criterion with seven only. After incorporating all groups of users, this results in an aggregated weighting of 7.5 for this criterion.

Accordingly not all criteria have to be categorised as of similar importance. For instance, for the University of Vienna the organisational criterion "location" is, with a weighting of 30%, more significant than the criterion "identity" with only 10% (cp. table 1). Yet, the sum of all criteria of one column (e.g. economic criteria) always has to be 100%.

Table 1. The organisational criteria`s weighting.

Organisational criteria	Weighting
Location	30%
Identity	10%
Function	30%
Socioculture	15%
Operation	15%
Total	100%

2.2 *Quantification of criteria*

Following the criteria`s selection and weighting, it was also necessary for them to be quantified in some way. For this the method of epiqr®, the European system for the assessment of building stock, with which the technical criteria were examined, was used. epiqr® facilitates the comparatively fast survey of a building`s technical state by means of just a few basic data. Only the most important building components are being assessed with states from “A” (very good) to “D” (end of life span). Then the correspondent maintenance measures and costs are assigned to these states. Finally, the epiqr® diagram shows for each building where there is need for action und how much money has to be invested (cp. fig. 3).

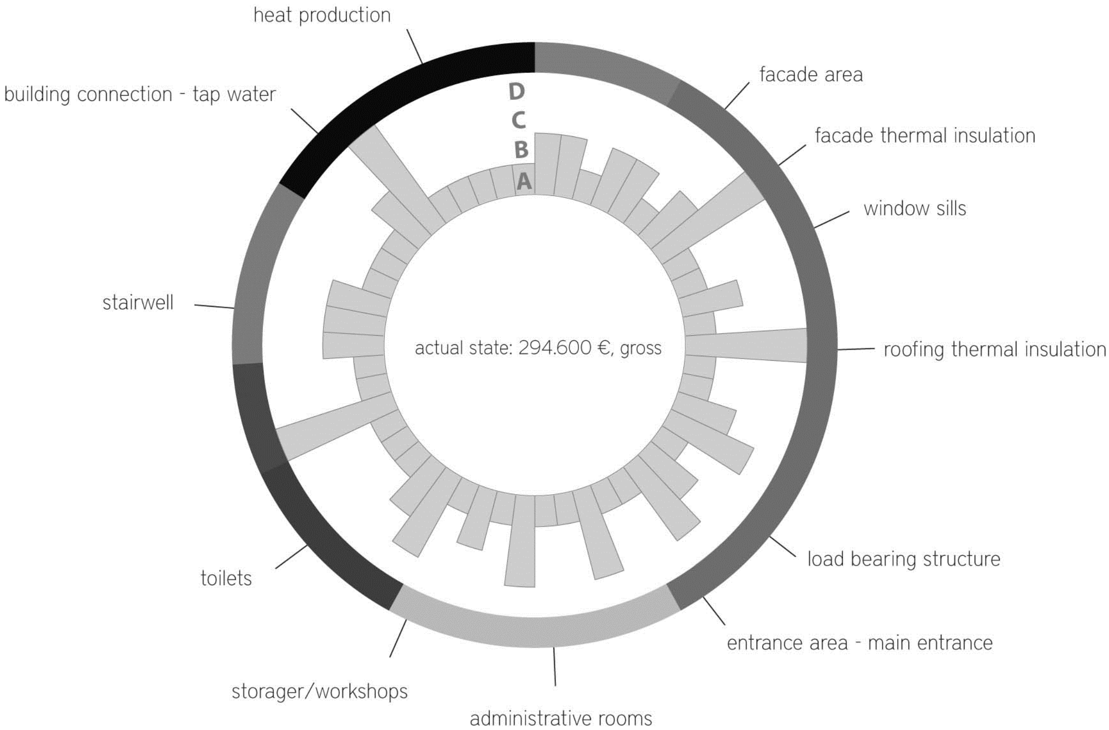

Figure 3. The epiqr® diagram shows a building`s strengths and weaknesses.

This system was adopted for the assessment of the organisational and ecological criteria, as four possible states were defined for each criterion. Quantifying economic criteria in this way was comparatively easy: for the costs of cleaning, for example, the annual expense per square metre gross net area was regarded. This served as an index number that could be assessed according to its amount. In case of the University of Vienna the state “B” commences with annual cleaning costs of 0.76 €/m2. State “C” is reached at 1.01 €/m2 and state “D” at 2.01 €/m2. The organizational criteria can be dealt with in just the same manner. Thus it was, for example, determined, that the criterion “access to bicycle track” should be evaluated as state ”A” if there is direct access, whereas state “D” begins with a distance of more than one kilometre to the next bicycle track. The exact classification is shown in figure 4.

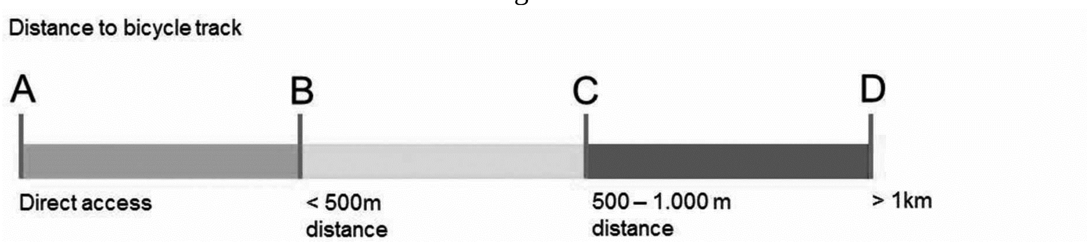

Figure 4. Definition of states for the criterion “access to bicycle track“.

With the help of these assessment criteria and based on the University`s development plan it was then possible to define an ideal building, that manifests optimal values for the technical state, lease costs, operating costs, space efficiency, organisational criteria, size and situation. In like manner critical values were defined for these criteria as well, marking the point from which a building no longer complies with the University`s requirements.

Then, analogue to the approach of epiqr®, measures were specified to improve those organisational and economic criteria that could be influenced. For buildings with an insecure access situation, for instance, constructional measures, such as the removal of elements affecting sight and the installation of exterior lighting, should be taken to ameliorate the situation. By then assigning each state the cost needed for its improvement, it was possible to monetize the assessment criteria (cp. fig. 5). In this way concrete prices can be allotted even to abstract criteria such as safe access. Accordingly not only an object`s technical but actually its complete investment needs can be measured.

State	Description	Measure	Cost
A	Safe access	No intervention	Omitted
B	Mostly safe access	Installation of additional exterior lighting, removal of elements affecting sight (bushes, panels)	€ 5.000
C	Mostly unsafe access	Constructional measures to improve the access situation (broadening of sidewalks, removal of elements affecting sight), installation of exterior lighting	€ 10.000
D	Unsafe access	Major constructional measures to improve the access situation (broadening of sidewalks, removal of elements affecting sight), installation of extensive exterior lighting	€ 15.000

Figure 5. The monetary assessment of the criterion “access safety“.

2.3 *The portfolio management tool*

After the technical, economic and organisational assessment of all of the University`s buildings, the data was transferred to a portfolio management tool. There its evaluation is carried out on object and portfolio level. On the object level all criteria for each building are displayed in the epiqr® diagram. This shows directly where the building has some backlog.

On the portfolio level the complete portfolio is being evaluated. For this the three classic columns of the assessment matrix, “rental success“, “object quality“ and “location“, were replaced by the three groups of criteria already introduced: “technical criteria“, “economic criteria“ and “organisational criteria“. In the portfolio diagram (cp. fig. 6) this results in a matrix with eight fields, in which the portfolio is segmented into clusters.

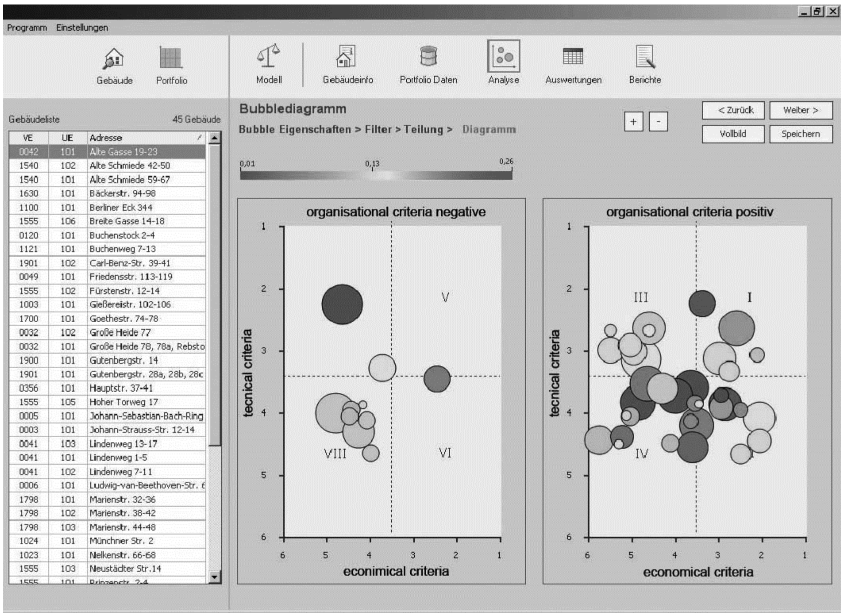

Figure 6. The clustering of buildings in a bubble diagram.

3 THE DEDUCTION OF DECISIONS

In the bubble diagram, represented above, the analysed buildings are allotted to the segments I to VIII, according to their values. For each segment exists a recommended course of action that is consistent with the University`s company-specific aims and additionally includes the building`s location and size. This results in a matrix, shown in figure 7, from which the portfolio strategy can be deduced. If, for instance, a building is located in sector VIII, this means it is in a very bad technical, organisational and economic state. Consequently divesting is recommended, if location and size are evaluated negatively as well.

SECTOR	Location and size very good		Location and size good/bad		Location and size very bad
I	Keep	Keep	Develop	Review	Sell
II/III	Develop	Develop	Develop	Review	Sell
IV/V	Develop	Develop	Review	Sell	Sell
VI/VII	Develop	Review	Review	Sell	Sell
VIII	Develop	Review	Review	Sell	Sell

Sector I: Technically, organisationally and economically very good

Sector VIII: Technically, organisationally and economically very bad

Figure 7. Matrix for the deduction of the portfolio strategy.

However, in such cases there is a possibility to veto if there are important arguments for the building to remain in the portfolio. Generally, the University of Vienna cannot part with its headquarters for politico-cultural reasons, although it might not fulfil the technical, organisational and economic requirements.

Thus, the portfolio management tool provides an overview over the whole portfolio, informing which buildings should be ceded and which ones further developed. Based on this information, short-, middle- and long-term strategies can be deduced for the utilisation or sale of these buildings. At the University of Vienna, besides 15 objects already ceded, 23 buildings were categorised as to be divested. Seven objects will remain in the portfolio in spite of their characteristics (the reason being the veto already explained), while 25 are in accordance with the requirements (cp. fig. 8).

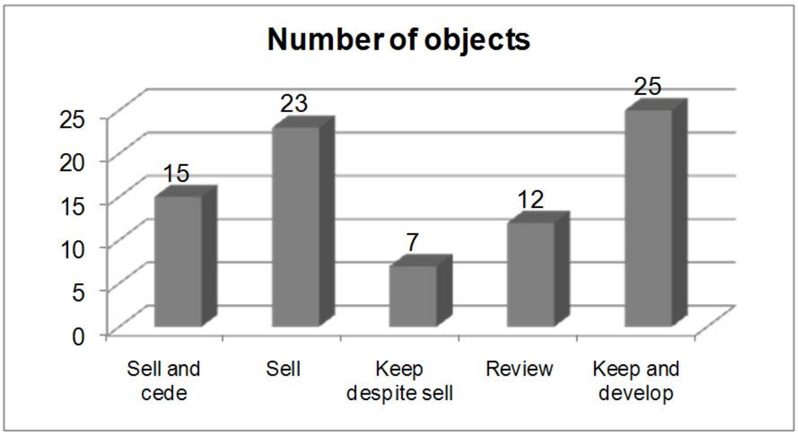

Figure 8. The distribution of the University`s objects according to the strategy.

4 CONCLUSION

With this new portfolio management system a portfolio can be assessed without, as customary, focussing on economic aspects alone. Considering sustainability as well and thus including all important elements, future portfolio decisions can be made much better informed. And as these decisions are based on a holistic assessment that also incorporates the diverging preferences of the various groups of users, alterations can be justified and thus accomplished.

Furthermore, it is possible to represent the consequences of alterations in the strategy for the portfolio and to assess the acquisition respectively leasing of new facilities. Thus, even a very heterogeneous portfolio as the University of Vienna`s can be optimised objectively and comparatively simply in a technical, economic and sustainable sense.

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Inspection and Diagnosis: A contribution to modern buildings sustainability.

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ABSTRACT: Through times has been witnessed an increase of constructive and functional anomalies in recent buildings, leading to deprivation of present and future sustainability of many of the existing constructions.
The significant increase in quality standards and energy efficiency of intervened buildings is the primary goal when employing a phase inspection and diagnosis during the initial stage of rehabilitation of buildings, since it's a unique way to interpret anomalies and their respective sources.
As such, this paper main objective is the presentation of an inspection and diagnosis study of a recent building in Lisbon city, supported by the identification and classification of events (anomalies, their causes, diagnosis and intervention proposal associated). Thus, it was developed a method quite advantageous and efficient regarding the EU 20-20-20 targets and the rehabilitation of existing buildings.

1 INTRODUCTION

In the recent decades Portugal has witnessed a paradigm shift in the construction sector, which involves passing the relevance of new construction into the rehabilitation and maintenance of buildings. As such, it is a growing consensus to extend the useful life of existing buildings (Brito, 2009).

According to Haapio & Viitaniemei (2008), a construction is in his useful life span, while it's able to meet the objective and subjective needs of the user, within the limits considered cost acceptable and without harm to third parties. In fact, when the buildings are targets of rehabilitation and maintenance activities, it is extended in an evident way the durability of the constructive elements intervened affording the increase of the buildings expected life span.

Despite the concern expressed in acquiring quality in construction, so coveted in certain circumstances, the most recent buildings do not have the desirable performance and durability, which is caused fundamentally by the early appearance of functional and constructive anomalies. In fact, in recent decades, there has been an increasing degradation of the recent buildings in Portugal. In the analysis of census produced in 2011, it can be verified an increase of 3.02% in recent buildings that need repair work, compared to results collected in 2001 census.

Due to the increasing complexity that is imposed in contemporary constructions, it becomes more difficult to point and define the reasons to justify the emergence of their respective anomalies. However, the non-use of a diagnosis system, antecedent to intervention activities, turns out to compromise in long-term the expected performance of the buildings in question.

According to Aguiar *et al*. (2006) and Ribeiro & Cóias (2003), once detected the existence of anomalies in a building is essential to know the causes and mechanisms involved to ensure that the repairing intervention is effective. So can be established the essential conditions to the acquisition of the respective solutions, whether they be of a corrective or preventive nature.

Since the way that rehabilitation is proceeded, in most buildings, is a key factor in their sustainability, it is essential to develop a correct interpretation of anomalies, supported by objective and adequate diagnosis means with the goal to increase significantly the quality standards and future energy efficiency of potential intervened buildings. However, the buildings inspection and diagnosis processes become quite complex, influencing inadequately the posterior decisions relating to the developing intervention measures (Aguiar *et al*., 2006). As such it will be essential the identification, classification and strategic planning of all stages of the processes in question.

Therefore, this text will be aimed at the presentation of an inspection and diagnosis study of a recent office building, built in Lisbon in 1990 with a reinforced concrete structure whom currently presents profound constructive and functional anomalies. The system of inspection and diagnosis, employed in the building, is qualified by the identification and classification of anomalies, causes that enhance their development, diagnosis methods used and intervention techniques proposal (corrective or preventive) posteriorly obtained.

It is intended to achieve, in an objective way, rational decisions regarding the repairing of anomalies in recent buildings, taking into consideration that these buildings requalification is one of the current biggest challenges in the areas of engineering and architecture from the perspective of the EU 20-20-20 requirements. Accordingly, the exercise that is presented, intends to be a small contribution to sustainability in buildings, meeting the balance between what is socially desirable, economically feasible and environmentally viable.

2 METHODOLOGY

According to Aguiar *et al.* (2006), developing a typification of anomalies causes is an extremely difficult task, possibly not achievable in a single and coherent way. Actually, developing inspection and diagnosis activities on large areas, such as recent buildings (constituted by a set of endless materials, technologies and processes), becomes a very subjective method involving a significant increase in complexity, discrepancy and hesitation in the stages of gathering information and obtaining diagnoses. As such, the methodology that was applied in this case study, had as fundamental features the objectivity, simplicity and coherence of the information progressively collected during the whole process.

In a first phase, it was conducted a collection of indispensable information about the building in study, by conducting user surveys, as well as through the acquisition of written documents and plants. After the appreciation and analysis of the information collected previously, it was initiated the activity of building inspection, starting from the general components to the anomalous situations particular of each construction element observed.

After a rigorous observation of all elements of the building needed to quantify and qualify during the initial act of inspection, began the diagnosis techniques elaboration process. Only with a coherent and conclusive interpretation of the analysis results from the previously used diagnosis techniques, will be initiated the selection process for intervention measures. Otherwise it will be necessary to reformulate the entire involving diagnosis process, in order to avoid the identification of illusory causes/sources of the respective anomalies initially observed.

Therefore it will be schematically and directly represented a methodology of inspection, diagnosis and intervention of anomalies in recent buildings (Fig. 1). However, only the first stage (Inspection and Diagnosis) of the flowchart in Figure 1, was held in the building in analysis, since the second stage of the process regards to monitoring and structuring phases for the concretization of intervention measures (pre-defined in the first stage of the process).

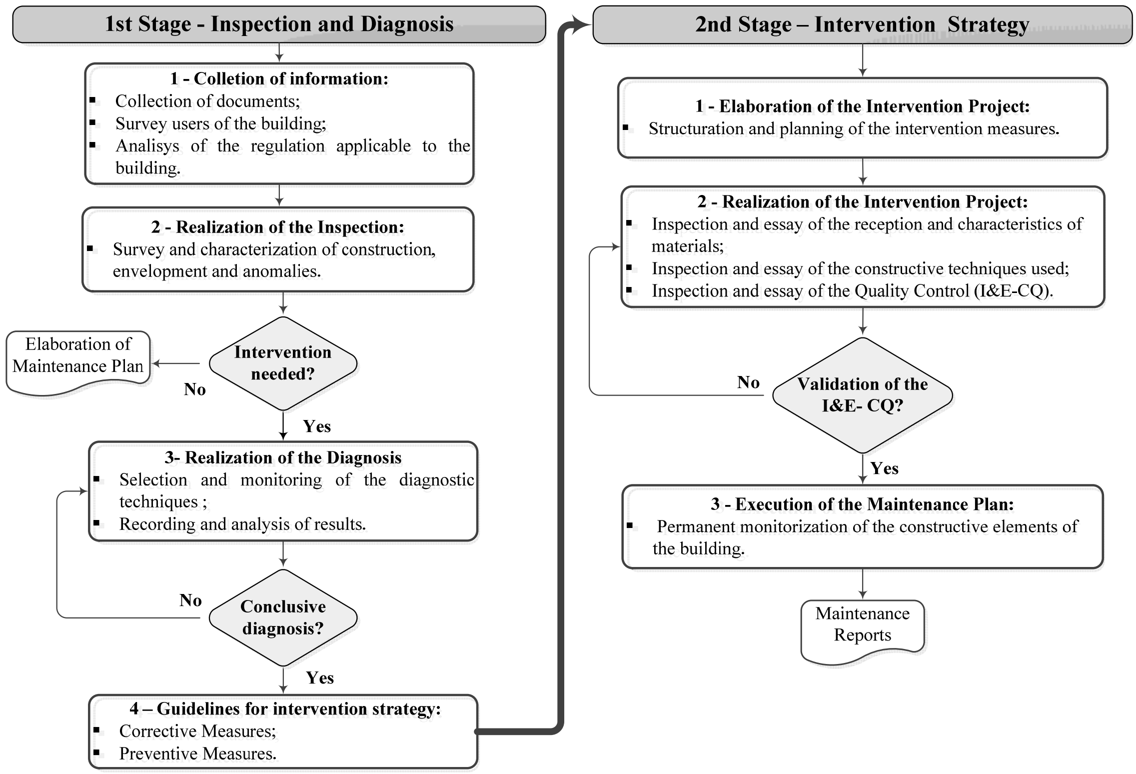

Figure 1. Flowchart a methodology of inspection, diagnosis and intervention of anomalies in recent buildings.

3 CASE STUDY

3.1 *Collection of information*

This case study is an administrative building in the center of Lisbon in the neighborhood of Pena, lying in the vacant state since 2009. The building was built in 1990 with three basements below ground level and ten floors above (considering the attic), making a gross building area with about 5488 m^2, and a rentable area with 5225 m^2. The structure is in reinforced concrete with the constructive typification of a recent building. In Figure 2 it can be observed some compartments of the building in study.

The underground floors are characterized by peripheral shaped containment walls associated with simple 15 cm thick brick masonry plastered and painted.. The interior walls are constituted by a simple 11 cm thick brick layer, finding the same plastered and painted with plastic paint. The underground floors pavement is coated with floor screed on the parking places, and ceramic mosaic in the compartments and sanitary facilities.

The upper floors are characterized, in most situations, by partitioning walls of removable type, with the exception of sanitary facilities, where there are simple 11 cm thick brick masonry plastered and painted with plastic paint. The exterior walls are constituted by double 7 cm thick brick masonry, with a 10 cm air box, unventilated and without thermal isolation filling, finding the same plastered and painted with plastic paint on the interior envelopment. Regarding the exterior facades, they are coated with a pinkish limestone, stabilized with staples. The pavements of the main administrative compartments on the upper floors are, in most cases, constituted by wood parquet floor varnished, ceramic mosaics (in sanitary facilities) or granite stone mosaics (in hallways). Regarding the typology of frames used in the front and rear facades, it was used a dark brown aluminum frame, with double glaze bronze colored windows (5mm + 5mm) and without thermal cutting.

Figure 2. Representation set of most floors compartments inserted in the building.

Considering the building seismic behavior, the vertical elements of great rigidity that are resistant in seismic situations are generally the stairwells and lifts. In conclusive results during the methodology of the proposed work in this case study, was taken into account the information provided in the urban documentation and plants with a 1:100 scale representation. However it was not afforded access to structure projects and original specialties.

3.2 *Inspection, Identification and Classification of Anomalies*

Regarding the qualitative summary evaluation of anomalous situations evidenced in the eighteen inspections made to the building in study, it can be noted that there is a great variety of anomalies types per floor, which are repeated from the second floor up, inclusive. In the three basements it's recurrent the observation of defined cracks at 45° in peripheral and partitioning walls (Fig. 3a), cracks without defined orientation, and in equal circumstances it can be observed efflorescence effect on interior walls (Fig. 3c).

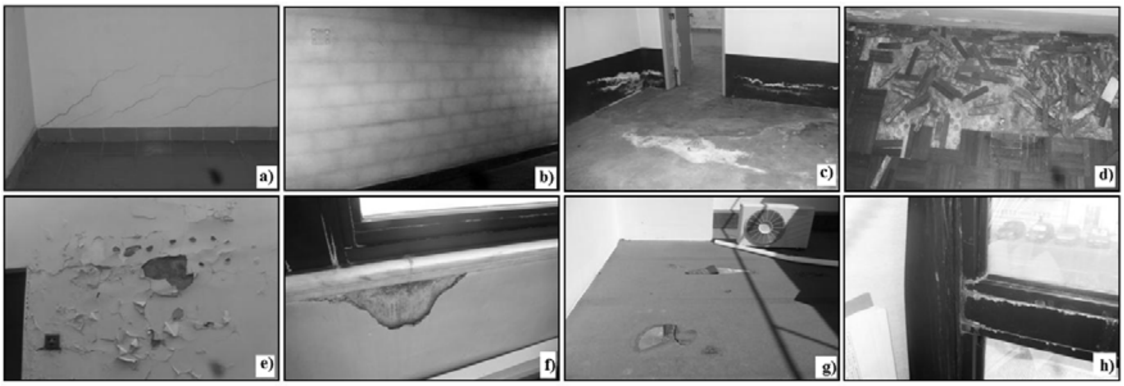

Figure 3. Representation set of abnormal situations detectable in the building in study.

Referring to the first and ground floors it's visible the permanence of anomalies in the wood pavement due to the flooding that occurred in 2011, leading to the degradation of the coating (Fig. 3d) and development of fungi. Also on the first floor its observable a punctual occurrence of plastic paint pellicle detachment (Fig. 3e) on a wall oriented south.

Given that the situations of exterior aluminum frame material degradation (Fig. 3h) are constant in all the above ground floors, such events tend to get worse from the second floor up, causing the walls plastering (Fig. 3f) detachment due to water infiltration.

Finally, it is important to mention the frequency of joints spectrums (Fig. 3b) in walls orientated north along the building, being also observable on the eighth floor terrace the deterioration and progressive detachment of the waterproof coating (Fig. 3g).

Given the immense diversity of anomalies present in the building, it was established an identifying classificatory system taking into account the type of building elements, and in some situations, the nature of the coating in which the anomalies were inserted (Tab. 1). As such, at this stage of anomalies identification it was sought the use of a clear and coherent classification system, developed through a logical organization of information, trying to avoid an exhaustive and repeated detailing of the data acquired along the process.

Table 1. Representation of the classification of anomalies evidenced in the building analyzed.

Classification of the anomalies by building elements	Description of the anomalies	
	Nomenclature	Designation
A. Anomalies in Interior and Exterior Walls	A.1	Structural Fissuration
	A.2	Non Structural Fissuration
	A.3	Paiting Detachement / Dustiness
	A.4	Eflorescence in the final coating
	A.5	Plaster detachement
	A.6	Appearance of joints spectrum in interior walls
B. Anomaly in Interior Wood pavement	B.1	Pavement detachement
	B.2	Fungal growth
C. Anomaly in stone pavement	C.1	Eflorescence in the surface
	C.2	Plant growth
D. Anomaly in stone wall outside	D.1	Eflorescence in the joints
	D.2	Coating degradation
E. Anomaly in Exterior Aluminium Frame	E.1	Material degradation
F. Anomalies in roof and terrace	F.1	Waterproof coating detachment
G. Anomalies in Pillars	G.1	Structural fissuration
	G.2	Paiting detachement / dustiness
	G.3	Eflorescence in the final coating
H. Anomalies in Pillars and reinforced concrete stairs support	H.1	Detachment and fissuration in Pillars
	H.2	Carbonation in Pillars
	H.3	Chloride presence in Pillars
	H.4	Fissuration on main stairs structure support

3.3 *Identification and Classification of Diagnosis Techniques*

In the present case study, we used various diagnosis methods (Fig. 4), taking into account the different types of building elements existing in the building in question.

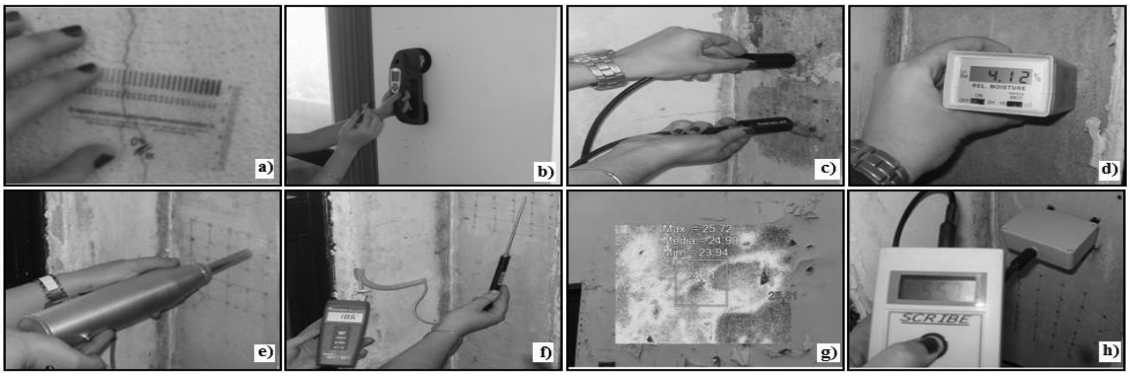

Figure 4. Representation set of the diagnosis techniques used in the building.

Thus in the exposed reinforced concrete construction elements it was used a esclerometer and ultrasound device (Figs. 4e, 4c) (for evaluating the mechanical resistance), a thermometer (Fig. 4f), an electrical resistivity measuring device (Fig. 4h) (to identify areas where the armatures corrosion is present or about to occur), the tests of phenolphthalein solution and silver nitrate (to investigate the phenomena of carbonation and the presence of chloride respectively), and a humidimeter (Fig. 4d). It's important to note the use of the pachometer (Fig. 4b), in reinforced concrete elements, as an aid to the inspection procedure and other diagnosis techniques (e.g. ultrasound). Regarding the exterior and interior walls of brick masonry, it was used essentially the fissure and/or cracks comparator (Fig. 4a) and a thermal camera (Fig. 4g), making also laboratory x-ray diffraction test, in order to identify the composition of salts from samples collected in situ.

In order to systematize the selection of the diagnosis methods used in the inspection, it is recommended that there is a classification of them (Tab. 2), in which, beyond the visual observation and the complementary means are also included the in situ nondestructive assays and the laboratory tests. The classification criterion recommended is the working principle of the technique, instead of the type of anomaly diagnosed or the location of the procedure.

Table 2. Representation of the classification of diagnosis techniques in the building analyzed.

Classification of anomalies by building elements	Description of anomalies	
	Nomenclature	Designation
Visual Inspection – Assisted Visual Analysis	TD-1-AVA-1	Fissures Comparator
Nondestructive *in situ* tests	TD-2-ND-1	Humidimeter
	TD-2-ND-2	Thermography
	TD-2-ND-3	Armatures Detector (Pachometer)
	TD-2-ND-4	Test of silver nitrate placement
	TD-2-ND-5	Thermometer
	TD-2-ND-6	Esclerometer
	TD-2-ND-7	Ultrasound
	TD-2-ND-8	Phenolphthalein test
	TD-2-ND-9	Electrical Resistivity Measurement
Laboratory Tests - Identifying the Presence of Salts	TD-3-IPS-1	X-Ray Diffraction

Given the information provided in Table 1 and Table 2 it will be presented bellow an example of a representation (Fig. 5), relatively to the location of anomalies and diagnosis techniques implemented on the second floor of the building in study.

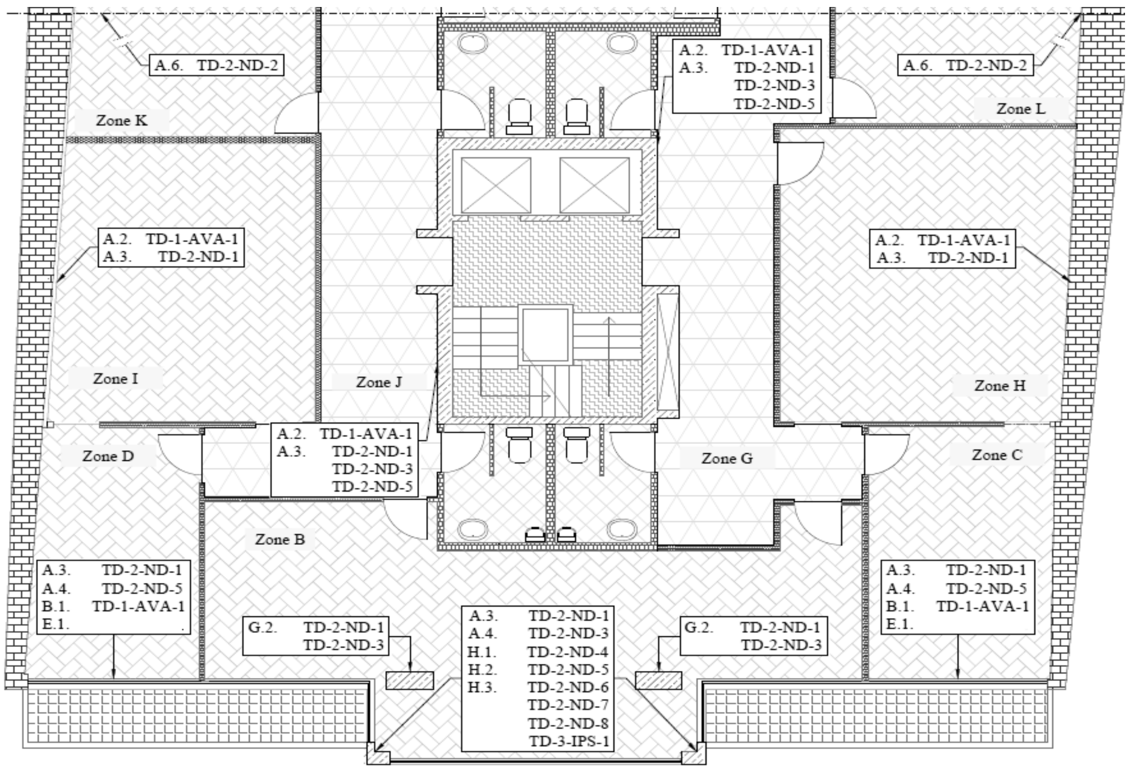

Figure 5. Designation and location of anomalies and diagnosis techniques, present on the second floor of the building in study.

3.4 *Selection of Intervention Measures*

Rehabilitation and maintenance techniques should also be subject to classification that takes into account two aspects: prevention (eliminating the anomaly) and correction (eliminating the cause). As such, in an early stage of the selection of intervention measures more suited for each anomaly evidenced, it was privileged the options for intervention of corrective nature, although in some situations it was appealed the use of preventive measures.

During the phase of guidelines establishment for the strategy of intervention of each anomaly evidenced it has been produced documents that contain the identification, description and location of the anomaly in question as well as the designation of the various diagnosis techniques used, the cause (s) associated with and finally some brief description (s) of the intervention proposal (s).

4 CONCLUSIONS

Regarding the results obtained from the inspections conducted on all floors of the building in study, it was found a total of 373 anomalous situations.

Given the division of anomalous situations by constructive elements, from Figure 6, it's possible to verify that localized anomalies in the interior and exterior walls are the most assiduous in the building, reaching 50% frequency of occurrence, in contrast with the anomalies present in the terrace and roof, which meet only 1 % frequency of circumstance. However the more observed anomalous situation in the development of the above ground floors in the building it's effectively the degradation of the exterior aluminum frames material, where such condition was assessed on 64 occasions, with an average observation frequency by floor equal to 7.

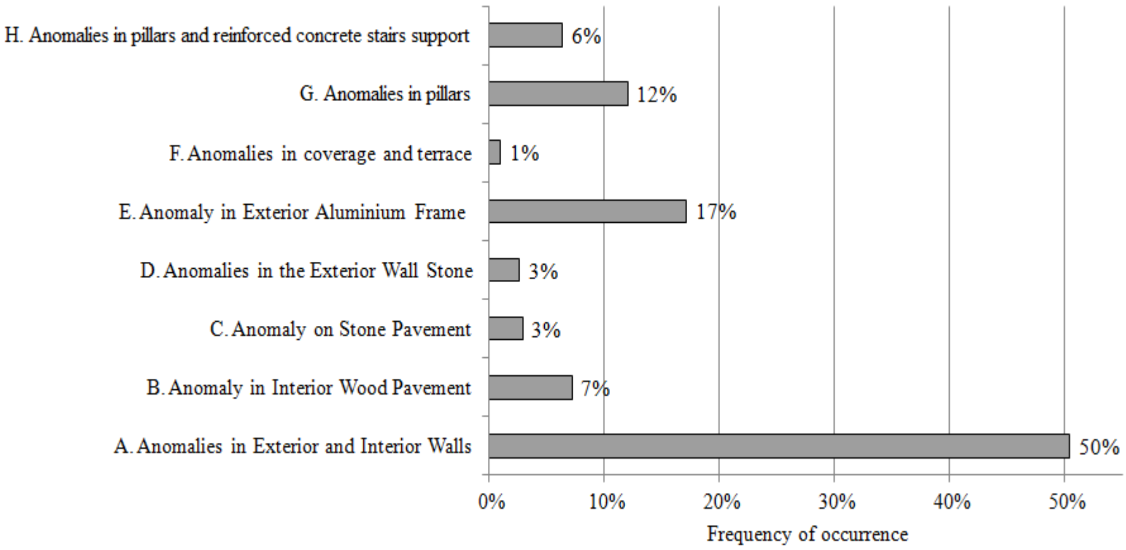

Figure 6. Representation of the proportion of anomalies evidenced by constructive elements.

Regarding the identification of the causes of the anomalies highlighted, about 30.56% of all anomalies emerged due to the poor quality of materials employed, in opposition to the occurring casualties during the utilization phase, only 0.80% (Fig. 7a). Despite such facts, it should be noted that, from all the anomalies, about 14.75% of them occurred derivative to human caused accidents (flooding on the first and ground floors). Regarding the frequency of the typology of diagnosis techniques (Fig. 7b), held in most building, the in-situ non-destructive tests were the most performed (72%). However , it was in the second floor where it was performed the largest number of diagnosis tests, about 46 in total, unlike the third lower floor, where it was held only 10.

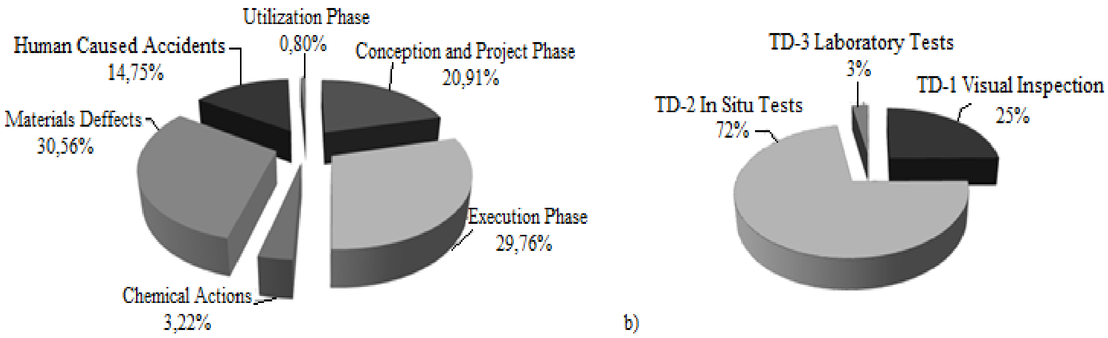

Figure 7. a. Representation of the distribution of causes associated with the observable anomalies; b. Usage distribution of the three types of diagnosis techniques.

Given the testing frequency, the measurement of moisture content on the walls coating and on the reinforced concrete surfaces was the most used diagnosis technique (Fig. 8), over all the floors of the building. It's relevant to mention that the visual inspection supplemented by photographic and video graphic inspection was the most used inspection method, where in some anomalies, served as a diagnosis method.

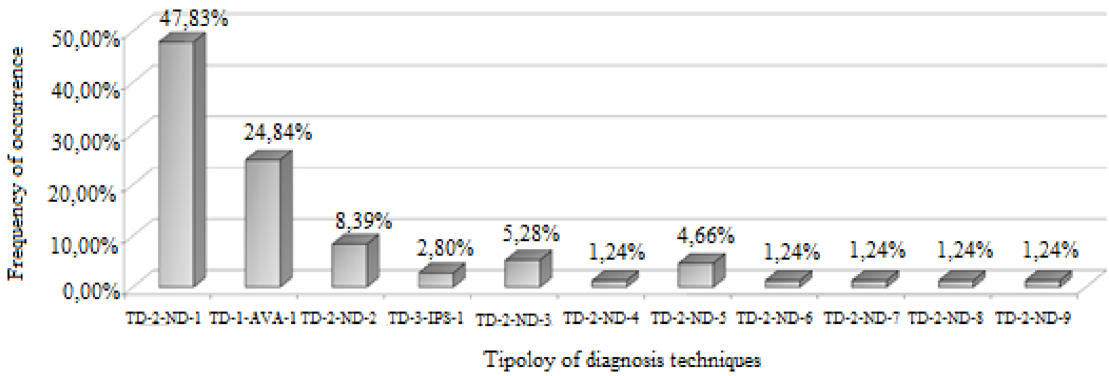

Figure 8. Representation of the utilization frequency of the diagnosis techniques.

It can be concluded that with the establishment of a plan of inspection and diagnosis in recent buildings (characterized by objectivity and consistency in the collection and organization of information available and acquired), provides in the long term, a range of advantages for the actual and future owners, since they can be aware of the causes/sources and effects of the anomalies, being able to choose with fundament the strategy measures of intervention more adjusted for each anomalous situation found in the analyzed buildings.

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Climate change effect on freeze-thaw cycles in Nordic climate

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ABSTRACT: In Finland one of the most considerable durability issues for outdoor structures is freeze-thaw cycles which can occur all year round. The biggest problems with freeze-thaw cycles occur while at the same time ambient conditions are wet. That is conventional in Finland during autumn, spring and warm winter when daytime temperature is slightly above 0 ^{o}C and by night below. The number of freeze-thaw cycles is slightly higher in inland than in southern Finland and coastal areas but the higher amount of rain and sleet in the latter makes the number of the freeze-thaw cycles needed for the same degree of frost damage much lower. This paper studies how the chance of freeze-thaw cycle occurrence effect on durability properties of concrete facades and balcony structures based on actual freeze-thaw durability studies by Tampere University of Technology and climate change projections made by the Finnish Meteorological Institute.

1 INTRODUCTION

1.1 *Finnish building stock*

Finnish building stock consists of 2.4 million buildings which include over 1.2 million residential buildings. Most of the residential buildings are detached houses in which almost half of the Finnish population live. Apartment houses are concentrated in big cities and they cover only 4.5 % of the total amount of the residential buildings. However 34 % of the population of Finland live in these housings. (ROTI 2011).

The volume of the renovation is increasing because the Finnish building stock is homogenous and fairly new compared to e.g. South and Middle Europe. Most of the stock is built after the 1960s. For example construction with precast concrete panels increased at that time because of the urbanization and most of it is built during the 1960s and 1970s. Buildings constructed at that time are coming at the end of their service life and they need to be renovated. Although the share of precast concrete panels and other concrete facades is only 18 % of all the facades its renovation volume is and will be significant within near future. (Lahdensivu 2010)

1.2 *Prefabricated concrete structures*

Since 1970s almost all prefabricated concrete structures in Finland are based on the Concrete Element System (BES 1969). That open system defines, for instance, the recommended floor-to-floor height and the types of prefabricated panels used. In principle, the system allows using the prefabricated panels made by all manufacturers in any single multi-storey building.

The concrete facade panels used in exterior walls of multi-storey residential buildings were, and still are, chiefly prefabricated sandwich-type panels with thermal insulation placed between two concrete layers. Facade panels are made up of two relatively thin reinforced concrete layers connected to each other by steel trusses. The thermal insulation between the layers is most often mineral wool of 240 mm nominal thickness according to the building regulations in force. It should also be noted that usually there is no ventilation gap behind the outer layers of precast exterior wall panels. Thus, if the thermal insulation gets wet e.g. due to leakage through the joints, the structure dries slowly. The drying of the outer layers is also slow because of the efficient thermal insulation that limits the drying heat flow through the wall. This means that the concrete may remain moist for long periods.

The most common balcony type in Finland from the late 1960's until today consists of a floor slab, side panels and a parapet panel of precast concrete. These stacked balconies have their own foundations, and the whole stack is connected to the building frame only to brace it against horizontal loads. All structural members of a precast balcony are load-bearing.

1.3 *Climate in Finland*

Finland is located between 60th and 70th northern latitudes. Its maximum length on north-south direction is over 1100 km and maximum width over 500 km. Yet Finnish climate is much milder than its location on mid-latitude predicts, mostly due to the warm and steady Atlantic Ocean. Also Scandinavian Peninsula prevents Finland for the most extreme conditions of e.g. coastal areas of Norway. In the Köppen Climate Classification system Finland locates in the subarctic climate zone in which warm summers and freezing winters are typical.

Although the climate is relatively steady for the latitudes and compared to size, it still varies considerably. However, the Finnish building stock is mainly focused on the few biggest cities and certain growth areas near them. Due to both the climate differences and the concentration areas of the population Finland can be divided to four main areas: coastal area, southern Finland, inland and northern Finland (Lapland region). Coastal area includes 30 km wide sector of the coast from the city of Vaasa to Russian border. Southern Finland includes the rest of southern parts to the level of the Tampere city (150 km north from Helsinki). Inland area includes the rest of the country except Lapland.

Prevailing wind directions and wind speeds also have a strong influence on the distribution of rainfall across a building. In Finland most of the rain and sleet in wintertime comes with southerly to westerly winds. Rain events with wind from other directions have been rare. Due to stronger winds, about 60% of the rain and sleet load in the coastal area hits the facades and balconies; the corresponding share inland is about 40%. Combined with the higher amount of precipitation in coastal areas, facades and balconies there are subject to considerably higher moisture stress than inland resulting in clearly more corrosion and frost damage. Winds are stronger at higher reaches of buildings than close to ground level which naturally leads to upper sections of high buildings receiving more rain and sleet stress than lower buildings, and lower sections of buildings in general. (Lahdensivu et al. 2013).

1.4 *Frost attack on concrete*

Frost attack due to a high moisture load is a common reason for the deterioration of concrete structures in Nordic outdoor climate. Concrete is a porous material whose pore system may, depending on the conditions, hold varying amounts of water. As the water in the pore system freezes, it expands about 9% by volume creating hydraulic pressure in the system. If the level of water saturation of the system is high, the overpressure cannot escape into air-filled pores and thus damage the internal structure of the concrete resulting in its degradation. More than 15 different theories or explanations for frost attack on porous materials have been presented (Kuosa & Vesikari 2000). That proves that frost attack is a complex process and frost damage can take many different forms.

The early phase of frost damage is manifested as inner cracking of concrete or scaling of the concrete surface when the hydraulic pressure caused by freezing pore water exceeds the tensile strength of concrete. Cracking will decrease the strength of concrete and increase capillary water absorption. Continuing freeze-thaw cycles and a high moisture content of concrete will finally lead to frost damage (Neville 1995). Early phase frost damage is not visible and cannot be detected by hammering the surface of concrete. Detection of such inner cracking of concrete requires a more sophisticated research method like thin-section analysis (Pentti et al. 1996).

Far advanced frost damage is manifested as a reduction in strength of concrete, loss of adhesion, or crazing or chipping off of the surface due to internal expansion. Disintegration of concrete also accelerates carbonation of concrete due to cracking and consequently also steel corrosion.

The degree of frost damage may vary in different parts of structures depending, for instance, on the moisture load and variation in material properties and thickness of the concrete structure. Frost damage due to a high local moisture load may affect only a very limited area. On the other hand, improper surface treatment of non-frost-resistant concrete may result in deterioration across most of the side wall surface.

2 RESEARCH MATERIAL

2.1 *Concrete facades and balconies database*

Research material for this study is composed of data on concrete durability assembled in condition assessments conducted on prefabricated concrete facades and balconies. The information has been collected as a database that includes the condition assessments of 947 buildings built in 1961–1996. As this study discusses the current concrete codes, only the data concerning buildings built 1990 or after are taken into consideration. There are in all 72 buildings from this era in the database. The database withholds measurements of concrete pore structure, tensile strength, chloride content, carbonation depths as well as concrete cover depths of reinforcement. In addition it includes results from thin section analyses and visual observations made from the building facades and balconies.

Practical design of concrete structures is in Finland governed by national concrete codes (BY50 2012). Besides guidelines for structural design, it also gives recommendation on durability properties and service life design. These requirements are compared to the actual observed degradation processes and their progress in the future.

2.2 *Climate data and projections*

The Finnish Meteorological Institute (FMI) has weather data since 1961 in digital form from several meteorological stations covering all of Finland. The data consist of temperature, relative humidity, rain intensity, wind speed and direction, solar radiation variables, etc. These observations have been collected at least daily and three times a day at best.

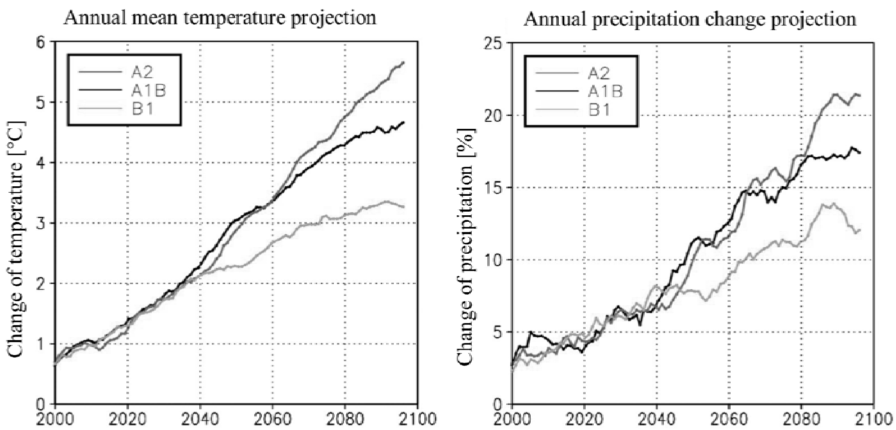

Figure 1. Projections for (a) the annual mean temperature and (b) the precipitation change for the period 2000–2100, relative to the mean of the reference period 1971–2000. The curves depict 11 year running means, averaged over Finland and the responses of 19 global climate models. Projections are given separately for the three greenhouse gas scenarios (A2, A1B and B1) (Jylhä et al. 2009).

In the ACCLIM project (Jylhä et al. 2009) the FMI examined the different climate models, built models for Finnish climate conditions and adaptation to climate change based on three IPCC (2007) scenarios for the evolution of greenhouse gas and aerosol particle emissions. Based on the scenarios the FMI has prepared their effects on weather conditions critical to concrete degradation (Fig. 1). In the REFI-B project (Jylhä et al. 2011), the FMI also forecast the climates of four localities (coastal area, southern Finland, inland, Lapland) in three periods (2030, 2050 and 2100). The forecasts are based on an average of 19 different models which are all based on greenhouse gas emission scenario A2. The A2 scenario involves a situation where greenhouse gases are assumed to increase significantly − it is a sort of worst-case scenario. The FMI also has other significant greenhouse gas emission scenarios: A1B (quite large emissions) and B1 (small emissions).

2.3 *Number of annual freeze-thaw cycles*

The number of annual freeze-thaw cycles in Finnish outdoor climate has been studied in four different weather stations: Helsinki-Vantaa (south coastal area), Jokioinen (south inland), Jyväskylä (inland) and Sodankylä (Lapland) with following criteria (Jylhä et al 2011):

- Raining or wet snowing at the most 2 days before freezing
- The number of freeze-thaw cycles when temperature goes under 0 °C, -2 °C, -5 °C, -10 °C, -15 °C, and -20 °C
- Counting the annual freeze-thaw cycles for the years 2000, 2030, 2050 and 2100

Table 1. Number of annual freeze-thaw cycles at four different observation stations at most 2 days after rain or sleet events (Jylhä et al. 2011)

Year and place	Temperature under (at most 2 days after rain or sleet)					
	0 °C	-2 °C	-5 °C	-10 °C	-15 °C	-20 °C
Vantaa (south coastal area)						
2000	37.8	23.5	11.7	4.0	1.3	0.2
2030	25.9	15.2	7.7	2.3	0.7	0
2050	21.4	12.9	6.1	1.8	0.3	0
2100	14.5	9.4	3.9	0.4	0	0
Jokioinen (south inland)						
2000	34.6	22.3	11.1	4.2	1.3	0.4
2030	26.5	16.0	8.2	3.0	1.0	0.1
2050	23.8	14.8	7.6	2.5	0.6	0
2100	17.2	11.3	5.8	1.1	0	0
Jyväskylä (inland)						
2000	30.4	20.2	10.4	4.2	1.6	0.5
2030	25.4	17.5	9.6	3.3	1.3	0.4
2050	24.8	17.0	9.4	3.2	0.9	0.2
2100	19.8	13.9	7.2	2.1	0.2	0
Sodankylä (Lapland)						
2000	23.4	18.1	10.4	5.0	2.7	0.8
2030	20.6	15.5	9.9	4.7	2.5	0.9
2050	22.3	16.7	11.4	5.8	2.5	0.9
2100	25.2	20.0	13.3	5.7	1.8	0

In table 1 the basic level of the number of annual freeze-thaw cycles in the year 2000 has been counted from the one hour intervals interpolated observations made during basic period of 1980-2009. Future scenarios bases model estimations where observed data has been changed to represent future climate.

Based on the research made by FMI, the annual rainfall will increase according to table 2. The change in the amount of rainfall will be higher during autumn and winter when drying of structures is slower in general.

Table 2. Average change [%] in precipitation compared to present climate (2000) in four different observation station.

	Vantaa (south coastal area			Jokioinen (south inland)			Jyväskylä (inland)			Sodankylä (Lapland)		
Month	2030	2050	2100	2030	2050	2100	2030	2050	2010	2030	2050	2100
1	4.1	9.9	29.6	4.3	9.3	24.7	3.8	9.7	32.6	6.2	11.5	37.9
2	6.4	9.5	29.3	5.7	9.5	26.0	6.3	10.8	30.5	8.4	14.4	31.4
3	3.9	6.5	20.6	2.7	4.1	15.3	3.9	6.6	21.5	3.3	8.4	26.7
4	3.4	6.5	19.1	0.7	4.1	14.1	2.3	5.8	16.4	5.2	9.3	21.2
5	3.5	5.9	16.6	2.2	3.7	11.4	3.9	5.3	14.9	3.4	5.5	22.0
6	-1.2	3.5	9.6	-0.8	4.3	11.2	-0.6	3.8	12.3	-0.9	5.0	17.7
7	2.6	4.4	11.3	2.6	5.4	12.8	2.1	5.1	11.1	2.9	4.7	8.4
8	3.8	4.9	5.7	3.6	3.1	4.3	3.5	4.5	5.8	4.6	5.4	12.2
9	3.5	5.8	9.5	2.7	4.5	10.0	4.4	6.7	11.0	2.3	3.4	13.2
10	3.1	8.4	18.6	2.9	8.3	17.9	2.8	8.0	20.1	2.2	8.8	22.6
11	7.1	10.9	24.4	6.3	9.5	22.3	7.9	10.6	27.6	7.1	13.1	30.6
12	5.4	9.0	28.7	4.8	8.1	23.7	6.5	12.0	34.0	8.1	15.3	38.6
Whole year	3.8	7.1	17.7	3.1	6.1	15.2	3.6	7.1	18.2	3.9	7.9	21.3

Again, according to FMI, the prevailing wind directions during rain events will stay same as present. It intends that facades faced from South-East to West will get more rainfall also in the future.

3 RESULTS AND DISCUSSION

3.1 *Frost resistance of concrete*

The frost resistance of concrete used in facades or balconies will be determined, in the first place, during concrete mixing process. Air entrainment to fresh concrete has been recommended since 1976 and demanded since 1980 in Finnish concrete codes. The compressive strength of concrete has been increased to present level (C30/37) as early as 1989 (BY32 1989).

Success of air entrainment of concrete used in facades and balconies was studied from the samples in the database taken on the buildings built 1990 or afterwards. In the database the information related to used air entrainment and its success has been reported as a protective pore ratio (p_r), which was common practice in Finland until the year 2004. According to concrete codes (1980), protective pore ratio should be at least 0.20, which intends that at least 20 % of total porosity of concrete never will be fulfilled by capillary water. Protective pore ratio 0.20 corresponds spacing factor 0.25 mm (Koskiahde 2004). The durability demands in different stress class according to Finnish concrete codes are shown in table 3.

Table 3. Demands for frost resistant hardened concrete in different stress class when designed service life is 50 or 100 years (BY50 2012).

Designed service life [a]	Stress class	Spacing factor [mm]	Freeze-thaw test	
			number of cycles	remaining bending strength after test [%]
50	XF 1	≤ 0.27	100	≥ 67
	XF 3	≤ 0.23	300	≥ 67
100	XF 1	≤ 0.25	300	≥ 67
	XF 3	≤ 0.22	-	-

Facades and balcony side panels and parapets belong to stress class XF 1 and balcony slab in stress class XF 3. The most common design service life is 50 years in ordinary buildings.

As can be found from figures 2 and 3, the air entrainment in fresh concrete has been made with varying success both in facades and balconies. The demand for frost resistance fulfills only approximately in 50 % of made panels. If the protective pore ratio is less than 0.1, concrete is not frost resistant in moisture conditions, i.e. in ordinary Finnish outdoor during winter time.

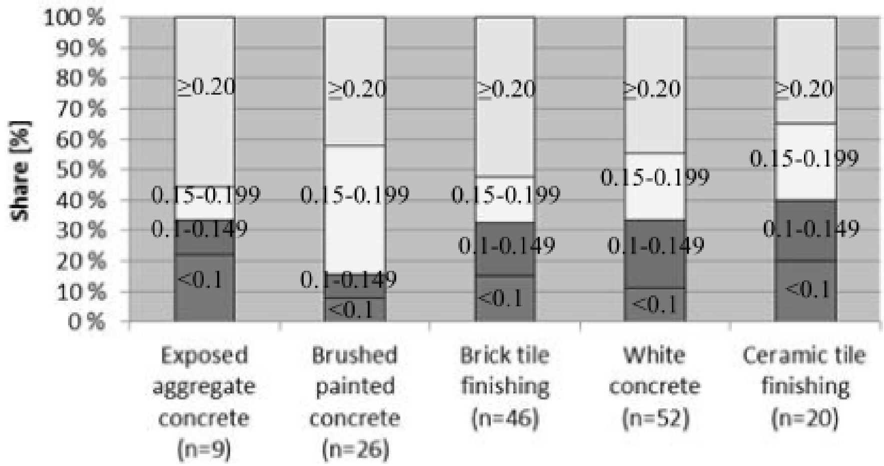

Figure 2. Distribution of protective pore ratios in different facade types according to database. The facades are made from 1990 to 1996. Total number of samples is 153.

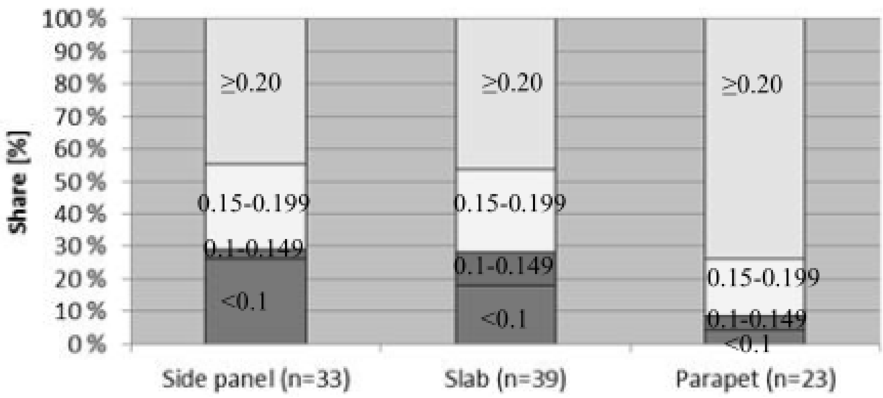

Figure 3. Distribution of protective pore ratios in different balcony elements according to database. The balconies are made from 1990 to 1996. Total number of samples is 95.

3.2 *Frost weathering of concrete*

Prerequisites for frost damage are that pore structure of concrete has been capillary fulfilled over critical point (Fagerlund 1977) and freezing of pore water will happen in the temperatures low enough (Pigeon & Pleau 1995). Thus, even if concrete is not frost resistant there will not occur any frost damage if concrete is dry or temperature does not go low enough. In practice, frost damage needs the concrete to freeze to temperatures of -5 ºC or lower.

The number of freeze-thaw cycles of existing concrete facades and balconies has been studied with following criteria (Lahdensivu 2012):

- raining or wet snowing at most 2 days before freezing
- the number of freeze-thaw cycles when the temperature goes under -5 °C
- studying the existence and state of frost damage with thin-section analyses (245 samples)
- samples from exposed aggregate concrete facades (no paint or other disturbing surface treatment).

Concrete can be very durable in Nordic climate if it has been successfully air-entrained. There were no signs of frost damage in the concrete samples according to thin-section analyses when concrete was frost resistant ($p_r \geq 0.20$) after over 500 freeze-thaw cycles in real outdoor environment.

On the opposite, if the protective pore ratio measured from hardened concrete is less than 0.10, the air-entrainment of concrete has failed. Even insufficiently air-entrained concrete has a service life of some years. Cracking indicating frost damage is the result of an average of 388 freeze-thaw cycles (t ≤ -5 °C) inland (Jyväskylä) and 307 cycles in the southern coastal area (Vantaa). If the freezing temperature criterion is t ≤ -10 °C, incipient frost damage occurs on average after 189 and 140 freeze-thaw cycles, respectively. On the southern coastal area this translates into about 22 years and inland into about 24 years. General frost damage revealed by thin sections begins to occur in exposed aggregate facades in the southern coastal area on average after 330 freeze-thaw cycles (t ≤ -5 °C) and after 416 cycles inland (Lahdensivu 2012). The number of freeze-thaw cycles is slightly higher in inland than in Southern Finland but the higher amount of rain and sleet in South Finland makes the number of the freeze-thaw cycles needed for the same degree of frost damage much lower. General frost damage in concrete samples revealed in thin-section analyses only approximately 20 freeze-thaw cycles more than incipient frost damage. So, the frost damage will proceed quite fast when it ever begins.

In table 4 has been calculated an estimation of the time needed for incipient frost damage revealed with thin-section analyses from inadequate frost resistant concrete both inland (Jyväskylä) and south coastal area (Vantaa) based on forecast of the future and above mentioned research.

Table 4. Time to incipient frost damage to reveal in thin-section analyses in different temperature criteria when rain or sleet has come ≤ 2 days before freezing (pr ≤ 0.10).

Building	South coastal area [years]		Inland [years]	
year	t ≤ -5 °C	t ≤ -10 °C	t ≤ -5 °C	t ≤ -10 °C
2000	26	35	37	45
2030	40	61	40	58
2050	50	78	41	59
2100	79	350	53	90

In consequence of climate change outdoor circumstances when concrete freezes wet will ease remarkably already 2030 in southern Finland. In inland outdoor climate remains in the present level and those will get even harder with increasing amount of rain and sleet almost to the end of century. The complete failure with air entraining fresh concrete (p_r ≤ 0.10) will surely lead to frost damage of concrete structure before eligible service life of the structure (usually at least 50 years).

If the spacing factor is less than 0.20 mm concrete can be generally considered as frost resistant in all cases (Pigeon & Pleau 1995). However, in several tests it has been found that concrete made of ordinary Portland cement is frost resistant if spacing factor is less than 0.50 mm (Powers & Helmuth 1953, Pigeon et al. 1986, Aitcin & Mindess 2011). In Finnish concrete codes required spacing factor is always 0.27 or less. It can be stated that according to present concrete codes tested durable concrete will stand well also in real outdoor climate for eligible service life.

4 CONCLUSIONS

The number of freeze-thaw cycles is slightly higher in inland than in Southern Finland but the higher amount of rain and sleet in South Finland makes the number of the freeze-thaw cycles needed for the same degree of frost damage much lower. In practice, frost damage needs the concrete to freeze to temperatures of -5 ºC or lower. Freezing events to -5 ºC are significantly fewer than freezing events to just below 0 ºC.

In consequence of climate change outdoor circumstances when concrete freezes wet will ease remarkably already 2030 in southern Finland. In inland outdoor climate remains in the present level and will get even harder with increasing amount of rain and sleet almost to the end of the century. The complete failure with air entraining fresh concrete (p_r ≤ 0.10) will surely lead to frost damage of concrete structure before eligible service life of the structure (usually at least 50 years).

Concrete can be very durable in Nordic climate if it has been successfully air-entrained. The present requirement for frost resistance of concrete is enough also in the future climate. However, the attention must be paid to successful air entrainment of fresh concrete. It must always succeed.

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Energy rating of windows for the cooling season: a proposal for Europe

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ABSTRACT: The proposed paper attempts to propose a new system for assessing the cooling performance of the windows at a pan-European level. The paper starts with a brief presentation of the existing window energy rating systems found worldwide. In order to propose a new rating system which can be applied across Europe, climatic zones were defined. A detailed analysis of the energy performance of the windows on every proposed climatic zone of Europe followed, conducted as the dynamic simulation of the energy needs derived by a plethora of different window alternatives (geometry, thermal and the optical characteristics of the window, orientation and use of the reference room used for the analysis). Based on the results, a rating system for the cooling energy performance of windows was developed, which can be used for their rating with regard to their thermal and optical characteristics for different orientations and climate zones of Europe.

1 INTRODUCTION

Towards the accomplishment of the 20-20-20 targets set in the recast of the European Directive on the energy performance of buildings, the building's sector provides many opportunities for action, since it is the largest user of energy and CO_2 emitter in the EU (EU 2010). In fact, the sector has significant potential for cost-effective energy savings, which will lead to a number of additional benefits, such as reduced energy needs, reduced import dependency and impact on climate, reduced energy bills, an increase in jobs and the encouragement of local development.

At the same time, the impact of windows, fenestration and glazed structures is becoming more and more important, since they combine many vital functions of the building (aesthetics, provision of view to the exterior, daylight, thermal comfort, protection against noise/ sun/ cold/ wind, safety, etc), which ask for properties that are usually conflicting and time variant, both diurnal and seasonal. Heat transfer through windows accounts for a significant proportion of all energy used in the energy sector, since the installation of cooling equipment in Europe continues to increase rapidly. At the same time, considerable advances have been made in window technology in recent times. The energy saving potential from windows is therefore very large.

Towards that direction contributes the energy rating and labeling of windows, which can provide consumers with the simple, straightforward information they need in order to make energy efficient decisions, facilitating thus the implementation of the Directive.

There is ongoing work in several countries with the aim of establishing a system for energy rating and labeling of windows, which would indicate the possible savings of an advanced window compared to a standard one. Currently, USA, Canada, Australia, New Zealand, Great Britain, Sweden, Finland, Denmark, Slovakia and the Czech Republic have adopted systems for energy rating of the fenestration products (Tsikaloudaki & Bikas, 2013). Above them, only Australia and New Zealand have taken into account the cooling performance.

It is worth mentioning that similarities appear on the rating and labeling schemes found in each continent; for instance, in USA and Canada the windows are labeled with regard to their thermophysical and optical properties, while energy efficient products are marked with Energy Star. For the countries of Oceania, the windows energy performance is assessed through the estimation of the impact of the examined window type on the heating and cooling needs of a typical house. By comparing these values with the one derived for the reference window type (single glazed aluminum window), heating and cooling stars are attributed and the percentage reduction on energy needs is indicated. In most European countries with an existing window rating scheme, a formula is usually used for calculating the energy balance at the level of the window or on the basis of a reference building; the formula employs the thermal and solar transmittance of the window and occasionally the infiltration through the window. Apart from the similarities in the calculation method, what is really surprising is that all existing schemes share the same philosophy as regards the label appearance, which obviously follows the EU energy label for white goods.

Based on these facts the idea for developing an energy rating and labeling scheme for windows that could be used all over Europe seems reasonable; the scheme will have to propose the energy parameters and the calculation methodology, upon which the rating will be based. The applicability of the rating scheme in every European region can be assured by the establishment of climate zones in the European region with regard to the climatic characteristics, as well as by including both heating and cooling energy needs in the calculations. Furthermore, the distinction between residential and office use is also essential, mostly due to the deviations between the air quality requirements and the ventilation patterns, as well as the internal heat loads and generally the usage profile.

In the present paper, the development of a rating scheme for assessing the cooling energy performance of windows in Europe is attempted. The calculation methodology presented in the next section includes the establishment of the climate zones used for the study, the definition of the energy parameters that were regarded as the basis of the analysis as well as the description of the parametric analysis, which led to the development of the mathematical formulas for the estimation of window cooling energy performance. The proposed rating scheme is introduced synoptically, by presenting the rating method and the arithmetic limits between the categories.

2 CALCULATION METHODOLOGY

2.1 *The establishment of climate zones in Europe*

Given that the objective of the current task is to establish climatic zones in the European region in order to study the thermal behavior of alternative building formations, the use of degree-day approach was considered as the most appropriate method, since it can be used for a quick estimation of the heating or cooling energy consumption of a building, especially when the utilization of the building and the efficiency of the heating equipment can be assumed constant (Hitchen 2013). The term heating (or cooling) degree days is defined as the positive deviation of the mean daily temperature T_m from a base temperature T_b, practically the outdoor ambient temperature, above which heating (or cooling) is activated to sustain the indoor temperature to a comfortable level:

$$HDD\ (or\ CDD) = \sum_{i=1}^{12} \left| T_m - T_b \right| \tag{1}$$

where T_m = the mean monthly air temperature; T_b = the base temperature.

The basic temperature depends on the constructional specifications of buildings and their application in research. For heating, the traditional degree-day or degree-hour procedure is based on a combination of theory and empirical observations and assumes that, on a long-term average, solar and internal gains will offset heat loss when the mean daily outdoor temperature is 18.3°C and that energy consumption will be proportional to the difference between the mean daily temperature and 18.3°C. The applicability of this procedure is limited to residential buildings, where envelope transmission and infiltration are the dominating factors contributing to the building load (Papakostas & Kyriakis 2005).

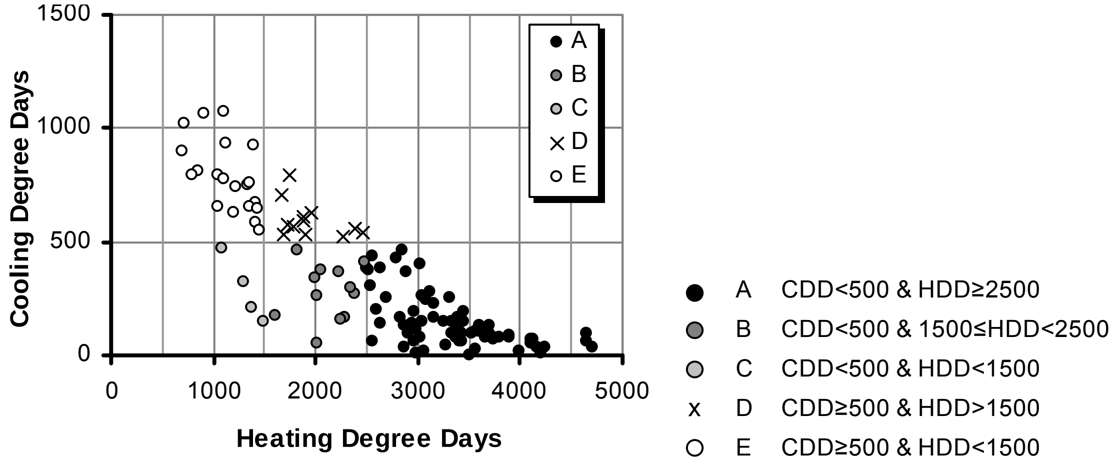

Figure 1. The proposal for establishing climate zones in Europe on the basis of the heating and cooling degree days.

Within the context of this objective, the cooling and heating degree days of selected cities across Europe were calculated at a base temperature of 18°C. The cities were selected on the basis of their population and availability of climate data. More specifically, all cities with a population over 100000 inhabitants were taken into account and among them, only 121 fulfilled the criterion of climate data availability.

Based on the climatic conditions prevailing on the selected European cities, a categorization into zones was proposed according to the region's heating and cooling needs, which are depicted by the number of Heating Degree Days and Cooling Degree Days. The value of 500 CDD was regarded as the threshold, above which the climate can be characterized as cooling dominated; the value of 2500 HDD (also found in literature) was regarded as the border for heating dominating climates. Lower values of HDD and CDD indicate lower energy needs for heating and cooling respectively. The proposed scheme is presented in Figure 1.

The cities with a cooling dominating climate (zones D and E) are located at the southern part of Europe and along the coastal regions of the Mediterranean. Climate zone C includes the selected sites from Portugal, where according to the climate data used in the analysis the climate seems to be mild, both during the winter and the summer periods. Zone B embraces the continental areas of Italy and Spain as well as the coastal areas of northern France and Spain. The remaining cities comprise zone A and are characterized by their wintry weather. It must be mentioned that a more analytic distinction could be made for the heating dominating sites; however, this research focused on the cooling performance of windows, which is not very essential for the overall building energy performance in cold regions (Tsikaloudaki et al. 2011).

2.2 *Definition of the energy parameters*

Cooling energy performance was assessed through the calculation of the cooling energy index, q_c, which represents the energy contribution of the rated window. It is calculated as the difference between the annual needs for covering the cooling requirements of the reference room with the examined window system and the annual needs for cooling requirements of a notional room, which is identical to the reference one, but its window is adiabatic (U=0) and non transparent to solar radiation (g=0), divided by the window surface (Tsikaloudaki et al. 2012a, b).

Therefore, the energy index for cooling, q_c is derived as the difference between the cooling loads estimated for the reference room with the examined window on an annual basis, Q_c, and the cooling loads estimated for a notional room, which is the same as the reference room, but its window is covered with a material that prevents heat transfer (U=0 W/m²K) and admission of solar gains (g=0), Q_{c,no_win}, divided by the are of the window, A_w (ISO 2011):

$$q_c = \frac{Q_c - Q_{c,no\_win}}{A_w} \tag{2}$$

The cooling energy needs of the reference unit, Q_c and Q_{c,no_win}, were calculated with the help of Energy+, an energy analysis and thermal load simulation program, which enabled the detailed dynamic analysis in every case. Energy needs are preferred to energy consumption, since there are various HVAC systems, which actually differ enormously from country to country. The philosophy of this methodology is in accordance with ISO 18292, which mentions that "the window energy performance for cooling ($EP_{C,w}$) is expressed through the energy needs per unit area of the window per year that is the contribution of window to the energy needs of the reference building for cooling" (ISO 2011).

2.3 *The reference room*

The cooling needs derived for each examined window were calculated for a reference room, the geometry of which is defined in EN 15265 (CEN 2007a) and ISO 13790 (ISO 2008). The reference room is of rectangular plan, 3.6m wide and 5.5m long, with a storey height of 2.8m. This configuration was selected as it was assumed that both an office and a residential building could be formed by the multiplication of the reference unit.

For the analysis, all opaque building components of the reference room were regarded as adiabatic, with the exception of the front wall, which was regarded as thermally insulated with a 0.05m layer of EPS (λ=0.04 W/(m K)) positioned on its external surface. The window is located on the front wall and covers an area that varies from 10% to 99% of the façade.

Two usage profiles were taken into account; as regards office, it was assumed that it is occupied during the working days of the week (Monday to Friday) from 07:00 till 17:00 all year long. Only during this operating time the HVAC systems are in operation. The cooling and the heating set-points were considered equal to 24.5^{o}C and 22^{o}C, in accordance with EN 15251 (CEN 2007b). Internal loads were regarded equal to 132Wh per day, which account for 13.76W/m² during the operating time and 2 W/m² for the remaining time. Ventilation varied from 0.8ACH to 1.50ACH for Mediterranean countries, while for the rest of the Europe it was considered equal to 0.50ACH. In order to take into account the increased air permeability commonly found in the Mediterranean structures, infiltration was considered equal to 0.50ACH for the specific zone and 0.2ACH for the rest of Europe.

For the residential usage, a full occupational status was taken into account. The cooling set point was considered equal to 26^{o}C in accordance with EN 15251 (CEN 2007b). However, it was assumed that the user would open the window when the indoor air temperature exceeded 24^{o}C with the condition that the ambient air temperature is lower than the one in the interior. In that case, ventilation was regarded equal to 2ACH. With closed windows a ventilation rate of 0.7ACH is required for air quality requirements. Infiltration rate was considered equal to 0.50ACH for the Mediterranean regions and 0.2ACH for the rest of Europe, in order to take into account the increased air permeability of the conventional structures found in the Mediterranean region. The internal thermal loads were considered equal to 5W/m².

2.4 *The variables of the parametric analysis*

For both cases (office and residential usage) alternative scenarios were studied, which differentiated mainly on the fenestration properties and the facades characteristics. As regards the fenestration properties, window products with different thermal and optical properties with respect to their frame fraction were studied. The selected values for the thermal transmittance of the window U (Table 1) cover a wide range of conventional and advanced fenestration systems; they range from 0.72W/m²K (passive window) to 3.20W/m²K. Both high (e.g. 0.76) and low (e.g. 0.30) values of the solar transmittance of the glazing g_{gl} were taken into account for each window (apart from the passive window). The solar transmittance of the whole window depends on the area of the transparent element; therefore the changes in frame fraction from 10% to 30% resulted in different values of g, as presented in Table 1.

As regards the façade's characteristics, different window sizes and orientations were studied. It was assumed that the window was positioned on the main façade of the room and covered 10%, 25%, 50%, 75%, 90% and 99% of the façade. It was also assumed that the window and the façade faced the four cardinal orientations, i.e. they were orientated due South, North, East and West.

Table 1. The thermophysical and optical properties of the examined window types.

Window type	U-window W/(m²K)	g-glazing -	Frame fraction %	g-window -
Type 1	3.20	0.76	10%	0.684
Type 2	3.20	0.76	20%	0.608
Type 3	3.20	0.76	30%	0.532
Type 4	3.20	0.30	10%	0.270
Type 5	3.20	0.30	20%	0.240
Type 6	3.20	0.30	30%	0.210
Type 7	2.60	0.76	10%	0.684
Type 8	2.60	0.76	20%	0.608
Type 9	2.60	0.76	30%	0.532
Type 10	2.60	0.30	10%	0.270
Type 11	2.60	0.30	20%	0.240
Type 12	2.60	0.30	30%	0.210
Type 13	2.00	0.67	10%	0.603
Type 14	2.00	0.67	20%	0.536
Type 15	2.00	0.67	30%	0.469
Type 16	2.00	0.30	10%	0.270
Type 17	2.00	0.30	20%	0.240
Type 18	2.00	0.30	30%	0.210
Type 19	1.37	0.60	10%	0.540
Type 20	1.37	0.60	20%	0.480
Type 21	1.37	0.60	30%	0.420
Type 22	1.37	0.30	10%	0.270
Type 23	1.37	0.30	20%	0.240
Type 24	1.37	0.30	30%	0.210
Type 25	0.72	0.40	10%	0.360
Type 26	0.72	0.40	20%	0.320
Type 27	0.72	0.40	30%	0.280
Type 28	5.81	0.86	10%	0.780

The parametric analysis described above was conducted for 15 selected cities, which were representative of the zones described in chapter 2.1. For the coldest zone, the climate files of Aberdeen, Berlin, Stockholm, Tampere and Warsaw were included in the analysis. The continental Europe was represented by Belgrade, Bilbao, Brussels, Madrid and Milan, while for simplicity reasons zones C, D and E (described in 2.1) were integrated in one and were represented by Athens, Larnaca, Lisboa, Malaga and Rome. The climatic data were retrieved from the extensive database of meteorological information of Energy+. For most of the cities the IWEC (International Weather for Energy Calculations) database was used.

Additionally, two cases of thermal mass (heavy and medium) were taken into account for the analysis, in order to include the influence of thermal inertia on the cooling energy needs.

It is worth mentioning that for the office occupancy the results of 40320 simulations were used in the analysis, which accounts for 13440 cases for each climatic zone and 2688 for each examined city. For the residential use, the above mentioned numbers are reduced to half, as ventilation was not regarded as an independent parameter in the analysis. Totally 60480 simulations were run for the parametric analysis, resulting to a reliable and consistent sample for the statistical analysis.

3 RESULTS OF THE ANALYSIS

3.1 *The cooling performance of the windows*

The extensive parametric analysis offered a plethora of significant results, which mainly focused on the contribution of the window's characteristics on the energy balance of the reference unit regarding mainly the cooling loads. This contribution was found to differentiate substantially among the climate zones, the usage profile, the orientation and the window properties.

More specifically it was found that the cooling index reaches much higher levels for the Mediterranean countries, while for the continental Europe the respective values are reduced by at least one half or even one third. For the Northern European cities, the analysis showed that they cooling loads are very limited, resulting to very low or even negative values of cooling energy index, q_c.

Concerning the usage profile, it was found that the cooling energy index of the windows is more substantial when the ventilation is controlled, which is usually met in office buildings. For the residential buildings, the free ventilation pattern taken into account facilitates the dissipation of warm air towards the ambient environment; in these cases, the windows play a less important, but still significant, role in the formation of cooling loads. In fact, in such cases the solar transmittance of the windows is of greater importance, while for the office mode the role of the thermal transmittance acquires some magnitude. For both uses, the general impression is that the cooling energy index of the windows acquires lower values when the U- value of the window is increased and the g-value of the window is reduced. This practically means that the window is responsible for the increase of cooling loads when its U-value is low, since it prevents the heat flow towards the ambient environment when its air temperature is lower. On the contrary, a low g-value will lead to less solar heat gains through the window, leading to a better cooling performance for the window. Among the two major properties of the window, the solar transmittance seems to be the key for optimizing the cooling energy efficiency. This conclusion is less evident for windows with a North orientation, due to the lower solar radiation incident on Northern façades. The analysis and the justification of all derived conclusions on the cooling energy performance of windows have been presented in previous publication of the authors (Tsikaloudaki et al. 2012a, b).

3.2 *Predicting the cooling energy performance of windows*

The extensive simulation results offered the prospect of employing the statistical analysis for developing formulas that will express the cooling energy performance of windows. Within this context, statistical analysis was conducted with the help of R software. From the results it is derived that among all the parameters that affect cooling energy performance of windows the occupancy status, the climatic characteristics, the orientation, as well as the thermophysical and optical properties of the window play the most important role.

Since there is a strong correlation between the dependent and the aforementioned independent parameters, it was attempted to develop a simplified formula for each occupancy, climatic zone and orientation. The formulas are derived with the help of regression techniques. Regression was conducted to the mean values of q_c calculated for each one of the 28 window types (Table 1). The independent parameters that are taken into account in the analysis are the thermal transmittance U_w and the solar transmittance g_w of the window.

Analysis showed that in all cases the most appropriate model is of the form:

$$q_c = b \times U_w + c \times g_w \qquad (3)$$

where q_c = the cooling energy index of the examined window; U_w = the thermal transmittance of the window; g_w = the solar transmittance of the window; b and c = the coefficients derived from the statistical analysis and are given in Table 2 together with the values of adjusted R.

3.3 *The proposed rating scheme for cooling energy performance of windows*

In general, there is no standardized procedure for defining the limits of the energy categories. In order to propose a rating scheme, a basis for the comparison of the cooling performance should be formed. Given that the examined fenestration types are regarded as representative to the one met in the European constrictions, it is logical to categorize their performance with regard to the best (lowest q_c) and the worst (maximum q_c) behavior.

Within this context, the minimum and maximum values of q_c of the 28 window types were retrieved and their difference was calculated ($d=q_{c,max}-q_{c,min}$). The calculated value d was divided to three, in order to create 4 categories; the borders between the rating categories were set by adding d/3, 2d/3 and d to the $q_{c,min}$. The derived limit values between the rating categories are presented in Table 3. Following this approach, more categories could have been formed.

Table 2. The coefficients b and c used in equation 3 for every use, climate zone and orientation.

Use	Zone	Orientation	b	c	Radj.
Office	Mediterranean	South	-27.6	567	0.995
		East	-18.1	537	0.998
		West	-17.1	481	0.997
		North	-10.4	191	0.998
	Continental	South	-28.0	376	0.989
		East	-21.7	334	0.995
		West	-21.9	325	0.993
		North	-15.1	132	0.984
	Northern European	South	-21.5	243	0.980
		East	-17.0	187	0.983
		West	-16.9	183	0.979
		North	-9.5	64	0.915
Residential	Mediterranean	South	-8.6	333	0.974
		East	-7.9	390	0.994
		West	-6.1	362	0.995
		North	-2.1	118	0.993
	Continental	South	-6.3	159	0.960
		East	-6.3	173	0.988
		West	-5.8	170	0.987
		North	-1.7	47	0.988
	Northern European	South	-3.9	65	0.928
		East	-3.1	50	0.955
		West	-3.1	50	0.964
		North	-0.5	7	0.950

Table 3. The limits of the rating categories of the windows regarding their cooling energy performance.

Use	Zone	Rank	Orientation			
			South	North	West	East
Office	Mediterranean	D	>245	>79	>252	>254
		C	174-245	55-79	183-252	188-254
		B	102-174	31-55	115-183	121-188
		A	<102	<31	<115	<121
	Continental	D	>136	>33	>129	>129
		C	87-136	16-33	85-129	87-129
		B	38-87	(-2)-16	42-85	44-87
		A	<38	<(-2)	<42	<44
	Northern European	D	>78	>12	>58	>58
		C	46-78	3-12	34-58	34-58
		B	14-46	(-7)-3	9-34	10-34
		A	<14	<(-7)	<9	<10
Residential	Mediterranean	D	>167	>64	>206	>206
		C	125-167	49-64	156-206	157-206
		B	84-125	33-49	106-156	107-157
		A	<84	<33	<106	<107
	Continental	D	>72	>22	>81	>81
		C	53-72	16-22	59-81	59-81
		B	33-53	10-16	38-59%	38-59
		A	<33	<10	<38	<38
	Northern European	D	>28	>39	>29	>28
		C	18-26	30-39	21-29	20-28
		B	9-18	21-30	12-21	12-20
		A	<9	<21	<12	<12

3.4 *The practical meaning of the rating scheme*

The proposed scheme can be used for the assessment of the cooling energy performance of a window by applying the coefficient values presented in Table 2, taken into account the properties of the examined window and the climate zone that it is going to be installed. The resulting value will be used for labeling the examined window via the limits presented in Table 3.

4 CONCLUSIONS

In this paper a proposal for the rating of the cooling energy performance of windows in Europe is presented. It involves the simplified formulas for the calculation of the cooling energy index, which serves as the critical energy rating parameter for windows, as well as the establishment of the cooling energy categories for the rating scheme. The detailed analysis showed that the rating should be based on the thermal and solar transmittance of the windows, since these parameters appear to have the most significant impact on the formation of cooling energy loads. Additionally, it was regarded necessary to determine the window performance not only with regard to the climate, but also with regard to the orientation of the window and the building use.

The merit of the current paper is that it provides an approach for rating the energy performance of windows at a European level, not only by assessing their contribution on the formation of heating loads, but also by taking into account their involvement into the cooling needs. By combining these two components of window energy performance, the selection of energy-efficient windows will be promoted, given the fact that for a significant part of Europe cooling has an equally important role in the building's energy balance.

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A Qualitative Assessment of the UK Green Deal: Enabling Energy Efficiency of Buildings by 2050

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ABSTRACT: The Green Deal is a market-driven framework for delivering domestic and non-domestic energy efficiency. It is established by the UK Energy Act 2011. It is being designed to address the market failures and barriers which limited the take-up of previous measures. It is intended to provide households and businesses with access to low cost finance for energy efficiency measures. To help shape the implementation, 22 pioneer companies from a range of sectors were selected to work with the Government. Under the framework, businesses, acting as registered Green Deal Providers are contracting with customers for the provision of energy efficiency works while ensuring that assessments and installations are carried out by accredited parties. Financial arrangements are also being made to facilitate the implementation. However, preliminary evidence suggests that there are inherent problems associated with the proposed framework. This study therefore conducted a desktop review of the proposals and also qualitatively assessed both the Green Deal provision (supply) and the mass consumer (demand) side of the current arrangements by interviewing key stakeholders. It further benchmarks this outcome against experience from one other EU country. The paper concludes with recommendations for process improvement and directions for future research as a precursor to engendering a sustainable approach and offering a best practice guideline to other EU countries.

1 INTRODUCTION

1.1 *Global Perspectives on Energy Efficiency*

Energy efficiency is high on the agenda of many nations today. In the United States of America (USA), residential building energy has been identified as a contributor to greenhouse gas emissions representing about 20% of the total energy consumption (Brecha, et al, 2011). Also, as a result of increasing concern about carbon dioxide emissions from power generation, high natural gas costs for generating electricity and rapidly increasing costs of constructing new power plants in the USA; energy efficiency programmes are being considered by utilities and regulators (Berry, 2008). In addition, some work had also been carried out in the USA towards the evaluation of a risk management investment strategy as an alternative to risk avoidance practices applied with payback thresholds (Jackson, 2010). The strategic tool so developed provides an Energy-Budgets-at-Risk or ERaB risk management analysis to convey more accurate energy efficiency investment risk information. As with most other countries, the long term investment returns on energy efficiency programmes imply that financial management planning requires careful attention at the micro and macro levels.

Other countries such as Brazil have launched the National Efficiency Programme which aims to gradually decrease energy consumption and save 106 Terrawatt Hours (TWh) by 2030. The programme comprises several components including: new metering standards, smart metering technologies and energy-efficiency campaigns (Anon, 2010). Malaysia's National Energy Developments were anchored key Policies, agencies, programmes and international involvements (Chua and Oh, 2010); whilst Singaopore embarked on a building energy efficiency labelling programme (Eang and Priyadarsini, 2008).

In Europe, countries such as: Portugal, Sweden, Lithuania, Slovenia the UK and others have embraced various energy efficiency programmes on a national scale (Al-Mansour, 2011). A recent research work in Portugal established six fundamental objectives for developing Energy Efficiency (EE) plans for countries (Haydt et al, 2013). These objectives included: (i) to minimise the influence of energy use on climate change, (ii) to minimise financial risk from the investment; (iii) to maximise the security of energy supply; (iv) to minimise investment costs; (v) to minimise the impacts of building new power plants and transmission infrastructures and (vi) to maximise the local air quality. In addition there were six respective attributes which included: (i) CO2 emissions savings; (ii) payback; (iii) imported energy savings; (iv) investment costs; (v) electricity savings; and (vi) total suspended particle savings. These objectives and attributes were therefore used to show the possible outcomes from some hypothetical EE plans for Portugal (ibid). Previous survey work in Sweden also provided evidence that for a vast majority of the Swedish homeowners, even though it was important to reduce their household energy use most of them did not immediately see the need to undertake household investment measures but were contended with no-cost measures (Nair et al, 2010). In a similar vein, a study in Lithuania (which typifies most of Central and East European countries) indicated that energy intensity is at such a high level that it causes financial difficulties nearly in all branches of energy (Klevas and Minkstimas, 2004). The output of the work thus led to outputs that contributed to the concept of state energy conservation and the conditions for successful mastering of renewable energy resources were proposed. In Ireland, also, policy measures aimed at increasing energy efficiency in industry has been proven to be effective by the development of the Large Industry Energy Network (LIEN) programme (Cahill and Gallachoir, 2012). Unlike countries such as: France, Norway and Canada where greenhouse gas intensity of electricity is low, there is increased policy attention on Energy Efficiency Improvement for energy security, energy productivity and fuel poverty alleviation as well as climate change and water and air quality concerns in the United Kingdom (UK) (Armstrong, 2010). The UK has thus committed to reducing its greenhouse gas emissions by 34 % by 2020 and by at least 80% by 2050 (relative to 1990 levels). Successive governments have thus introduced a range of energy targets, policies and interventions - including:

- Renewable Obligation Certificates (ROCs) for electricity suppliers – to reduce their reliance on fossil fuels
- Promotion of household energy-saving solutions through Carbon Emissions Reduction Targets (CERTS) and the Community Energy Saving Programme (CESP)
- Incentive schemes for micro-generation from renewable sources (e.g. Feed-in-Tariff and Renewable Heat Incentive)
- Tighter energy efficiency regulations for new buildings leading to almost Passive Haus levels by 2016
- Minimum Energy Performance levels of Grade E for all rented housing by 2018 and the ability for tenants to demand improvements from 2016.

One of the key issues for the UK is the age of the building stock. By 2050, it is estimated that 80% of the UK housing stock will still have been built prior to the tightening of energy efficiency regulations. Many of these homes currently have the lowest Energy Performance Certificate (EPC) rating and as fossil fuel costs continue to rise, more people will be forced into fuel poverty. It is on the basis of this that the Green Deal Programme was introduced by the UK Government to tackle building energy efficiency (DECC, 2011).

1.2 *Aim and Objectives of the Study*

The study aims to explore the status of the UK Green Deal (GD) and investigate the uptake and involvement in the programme by the various groups – using the UK Midlands as a sample area. These groups include: The City Councils, Registered Social Landlords (RSL's), Manufacturers/Potential Installers. The study also sought to examine the current perceptions of the GD programme. Through interviews with these organisations, the study sought to determine the level of awareness of the scheme (originally launched in October 2012, but fully introduced in January 2013). It also sought to know the views of the stakeholders in the implementation of the programme. Ultimately, conclusive remarks are made with a view to providing recommendations for a sustainable implementation of the scheme.

2 BACKGROUND - THE UK GREEEN DEAL INITIATIVE

The Green Deal is a market-driven framework for delivering domestic and non-domestic energy efficiency. It is established by the Energy Act 2011. It is designed to address the market failures and barriers which limited the take-up of previous measures. It is intended to provide households and businesses with access to low cost finance for energy efficiency measures.

To help shape the way that it works, 22 pioneer companies from a range of sectors worked with the Government - with the aim of providing a good customer experience from the outset. These were: British Gas, EON, SSE, ReEnergise Finance, Toriga Energy, Ampere GDP, Carbonlow Group, Enact Energy, Stroma, Yorkshire Energy Services, British Eco, Empower Community, Anglian Home Improvements, Mark Group, Carillion Energy Services, Willmott Dixon Energy Services, Keepmoat, Gentoo Group, Grafton Group, Insta Group, Kingfisher and SIG Group. Many of these companies are now at the forefront of the Green Deal, providing finance, advisors and installation.

2.1 *The Proposed Operational Format of the Green Deal*

Under the framework, businesses, acting as registered GD Providers are to contract with customers for the provision of energy efficiency works while ensuring that assessments and installations are carried out by accredited parties. The GD provider will also contract with the customer to put in place a finance package, with customer repayments made over an agreed period (up to 25 years) - paid as part of the electricity bill. Energy supply companies will in turn be required to pass on payments received. Importantly, when a customer moves from the property, the Green Deal debt remains with the electricity meter and the legal requirement to continue making repayments is passed onto the next bill payer. Where appropriate, Green Deal Finance can be combined with other funds, including Energy Company Obligation (ECO) to provide support for older properties/vulnerable households.

The programme also includes remote information and advice. The Golden Rule is that the GD charge attached to the electricity bill should not exceed the expected savings, and the length of the payment period should not exceed the expected lifetime of the measures (DECC, 2011). Details of the different GD roles are shown in Figure 1.

2.2 *The Key Players*

The GD provider market is expected to be diverse, with providers from sectors including facilities management, construction, retail, energy assessment and energy supply. Providers may focus on domestic or non-domestic markets and may also operate through partnerships with third parties such as local authorities and other social landlords.

A GD Finance Company has been established which includes most of the pioneer companies, 5 out 6 of the electricity supply companies, a number of finance organisations and 6 local authorities. Initial press statements suggest that the purpose of this is to create a vehicle to aggregate Green Deal financing and secure the best credit rating possible, in order to keep Green Deal interest rates low.

2.3 *Consumer Protection*

A Green Deal oversight body protects consumer interests by:

- Authorising Green Deal assessors, products, providers and installers
- Monitoring compliance with the Code of Practice

- Managing the use of the Green Deal Quality Mark
- Providing details on authorised assessors, products, providers and installers
- Managing advice, referrals and redress when something goes wrong
- Overseeing the Green Deal Arrangements Agreement (GDAA)

There is also an ECO administrator tasked with managing its implementation and produce guidance on compliance with the Carbon Saving and Affordable Warmth targets.

2.4 *The Proposed Green Deal Qualifying Improvements*

A range of building energy efficiency measures have been identified as part of the DECC consultation (see Table 1). To a certain extent, these build on earlier carbon reduction initiatives including Carbon Emissions Reduction Targets (CERTS) and the Community Energy Saving Programme (CESP).

Table 1: Proposed Qualifying Improvements (DECC, 2011)

Insulation	High Efficiency heating
Cavity wall insulation	Fan-assisted replacement storage heaters
Draught proofing	Flue gas heat recovery devices
Energy efficient glazing	High efficiency gas-fired condensing boilers
External wall insulation	High efficiency replacement warm-air units
High thermal performance external doors	Oil-fired condensing boilers
Hot water cylinder insulation	Under-floor heating
Internal wall insulation	Renewables
Roof insulation	Air source heat pumps
Room in roof insulation	Biomass boilers
Under-floor insulation	Biomass room heater (with radiators)
Loft / rafter insulation & loft hatch insulation	Ground source heat pumps
Heating controls/heat recovery	Micro combined heat and power
Cylinder thermostats	Micro wind generation
Heating controls	Photovoltaics
Shower waste water heat recovery devices	Solar water heating
Mechanical ventilation with heat recovery	Other Lighting systems, fittings and controls

3 THE RESEARCH METHODOLOGY

As part of this research, the main customers of the Green Deal (the Registered Social Landlords (RSLs) and the City Councils) were interviewed for their views on the programme. The interviews centred mostly on those in the west midlands, namely: Wolverhampton City Council, Birmingham City Council, Worcester City Council, Staffordshire City Council and Coventry City Council.

The 5 councils and 16 RSLs were successfully contacted and invited to take part in a telephone interview. All interviews were conducted on a confidential basis. Questions asked included the following: Have you heard of the Green Deal and do you understand what it is designed to do? Are you participating in the Green Deal? If no, why not? (If yes to Q2), What are your current arrangements within the scheme? In your view what are the current strengths and weaknesses of the Green Deal? Would you like to convey any other information regarding your views on the Green Deal?

35 manufacturers/installers from across the UK who deal with products that are currently part of the Green Deal were also interviewed. These companies were also invited to take part in a telephone interview. As was the case with the RSLs and City councils, all interviews were conducted on a confidential basis and the participants were asked similar questions as was relevant to them.

4 RESEARCH RESULTS OVERVIEW

The results are presented in two sections. Firstly, a descriptive analysis of responses identifies the number of participants in the survey and their industry sector. Secondly, a qualitative analysis looks in more detail at responses and identifies common themes where possible.

4.1 *Descriptive Analysis of Survey Response*

The 100% of the councils mentioned above took part in telephone surveys. Although, 5 City Councils had heard of the Green Deal, only 2 of these were proactive in engaging with it. RSLs were also interviewed. However, only 16 were willing to participate in the study. In all, one of the RSLs had not heard of the Green Deal and only 3 were participating in some fashion as at the time of the interview. Of the 35 manufacturers/installers interviewed, 27 had heard of the GD. However, of these 27, only 6 were actually participating in some form – either as Installers or knowingly providing materials to installers.

4.2.1 *Qualitative Analysis of Survey Response*

All the responses collated were analysed with a view to determine the following: general level of understanding of the GD; potential weaknesses and improvements suggested and the positive dimensions of the Green Deal.

4.2.2 *Understanding of the Green Deal*

All respondents who had confirmed that they had heard of the Green deal also agreed that they knew what it was about. This is due to working closely with colleagues from organizations such as Sustainability West Midlands, Birmingham Energy Savers, Energy Savings Trust, Homes & Communities Agency and other Local Authorities.

There was, however, concern that the awareness of it within the general public is extremely low. In reality, the understanding of Green Deal within the general population appeared to be near non-existent. Generally, people seem to be unsure of: what it’s for; why it’s set up the way it is; why they should need an assessment (and why this is so expensive).

The usefulness of the Green Deal help lines was also brought into question by one of the interviewees.

4.2.3 *Potential Weaknesses and Improvements Suggested*

There is currently only one finance group supporting the scheme. The implication of this is that people have little or no options for more suitable finance.

The jobs that the government had hoped would be created by the GD are yet to materialise as the current duties are still being performed through jobs already in the sectors. It is also feared that new openings due to the GD are likely to be few due to the very slow uptake.

Another concern is that other forms of loans and grants, such as ECO, have been seen as after thoughts - but the view is that these need to be made a stronger part of the GD to promote uptake. This funding also needs to be increased from £80 per tonne/CO2 up to £180 per tonne/CO2 to make it a viable help.

The RSLs, on their own part, do not appear to be convinced that the GD is the solution to the problem at the moment. Affordability was highlighted as a problem for many of their customers as it was not clear how tenants (who already pay for the maintenance of their home through their rent) would be incentivized ‘to pay a second time’ through their electricity bills.

Some RSLs have thus decided that the best way forward is to get the work done by themselves, claim ECO grants and pass the savings directly onto their occupants.

This appears to be a possible solution as one RSL had received enquiries regarding the GD but were put off by the charge and the idea of needing a survey. So far, they had received only one application from a housing stock of tens of thousands. The GD is thus not seen as having been created with social housing in mind.

All groups that were interviewed had an overall agreement that the GD appears to be an unnecessary complexity. It is overburdened with hoops to jump through and complicated. The GD should be more flexible in its approach but people are still more likely to get a loan for the work elsewhere.

A very few of the interviewees believed that the GD is too much in the control of ‘big players’ at the moment and that the market is not competitive enough.

The installers and manufacturers all agreed that there are too many hoops to jump through to make it worth their time to enter into the GD fold and that the interest rates involved are too high.

4.2.4 *The Positives*

There was a consensus that if the GD were to be re-organised, easier to gain entry to with less hoops/red tape and a more competitive market with lower interest rates; then the scheme would probably work better than as currently arranged. As it currently stands, the scheme is good for people who really need improvements (especially those in electricity based properties). The GD will help to stimulate growth in the market and in 5 years’ time when things have settled the finance will be useful for sorting the basics in houses. The extra time will also allow products and services to come down in price and therefore be included under the Golden Rule.

5 CONCLUSIONS AND RECOMMENDATIONS

The UK GD programme, like most other countries’ energy programme, is geared towards and national objective. Having established that the GD is part of the UK’s commitment to reducing greenhouse gas emissions, this study was commissioned to investigate the levels at which councils, social landlords and manufacturers/installers are entering into the new scheme. Using evidence provided by some of most likely investors of this scheme through interviews it has been determined that the uptake is very low. This is largely due to people not knowing enough about the GD or having poor views on it due to its current state; be this general advertising, financial or ease of use. There is a positive view of the future, but how long it will take until the scheme improves to be user friendly is unclear. In order to ensure that the take-off and sustainability arrangements for the Green Deal gives it the greatest chance of success, therefore, it is recommended that the final details cover the following issues: removal of barriers to entry for SME’s; effective promotion; clear timescales; clarity on buying / selling properties with a GD loan attached; detailed analysis of occupancy and energy profiles within the assessment tool; more ability to explore other Finance options by property owners/tenants; fewer barriers for potential customers; need to continuously benchmark/review the progress to ensure that it is delivering to targets. (Such reviews should be comprehensive enough to include: policies, processes, technologies and other significant elements of the programme). These measures will ensure that the GD enjoys a more successful uptake and also help to flagship the GD as a programme that could offer flagship exemplar to other European Countries.

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Dividing indoor comfort limits by climate zones and describing it as a curve for the benefit of passive and low tech architecture design.

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ABSTRACT: In the recent years great amount of research has been undertaken in the fields of thermal comfort indoors. It is largely accepted that in natural ventilated buildings where occupants are allowed to directly influence their environment, the comfort expectations tend to follow outdoor conditions. The adaptive comfort model relies on these observations and generated two major standards: EN 15251 focused on Europe and the ASHRAE 55-2004 worldwide applicable.
The first part of this paper introduces the ASHRAE 55-2004 and its background field research. The second part discusses the vantages and disadvantages of dividing the available comfort limits by climate groups for the benefit of climate responsive design. The last part presents evidence for a more suitable comfort limits' description through a single-curve function instead of the available braked-in-two-seasons linear model.

1 INTRODUCTION

Humphreys' research in the 1970s (Humphreys 1978) was pioneering in the field of so called Adaptive Comfort. Firstly he proved that comfort state is related with the experienced indoor conditions. Secondly, since in naturally ventilated buildings the indoor conditions vary according to the outdoor climate, he found out that comfort sensation varies according to the outdoor conditions as well. The formerly widespread belief that indoor comfort would be steady-state and independent from outdoor conditions, following only physiological efforts to maintain thermal balance, was objected by Humphrey's work. Unlike the existing theory of thermal balance, which refers only to experiments in a climatic chamber, Humphrey's research is based on field surveys.

In the years that followed, many other field surveys have been undertaken in different climate zones and building types, which supported the adaptive hypothesis.

2 RELATED WORKS

In 1997 the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) commissioned a number of field surveys, which originated the RP-884 database (De Dear et al 1998) and later led to the first standard in adaptive comfort: ASHRAE Standard 55-2004. This Database contains the results of worldwide surveys mainly performed in office buildings.

Since 2007 the ASHRAE 55-2004 has a European counterpart: the EN 15251. Considering the research design, the basic differences are the criteria how to classify buildings (type or operation modi) and the methods to calculate both the comfort temperature and the outdoor tempera-

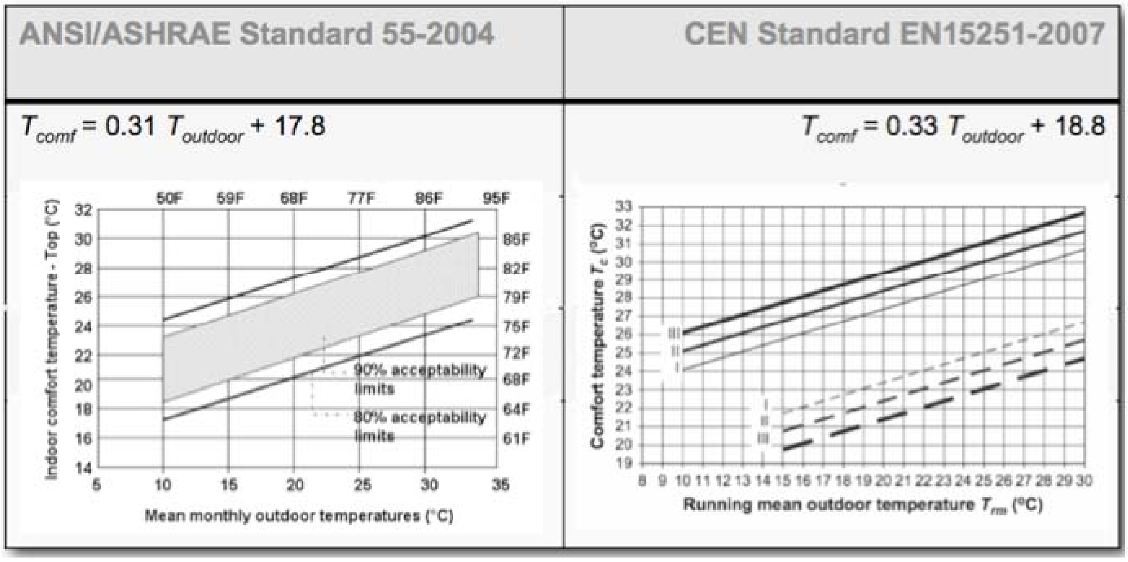

Fig. 1 – Comparison between two adaptive comfort limits in the major comfort standards (De Dear 2011)

ture. Both of the comfort models have been developed on the base of research in office buildings, however they are intended to be applied to all sedentary activities including dwelling.

Despite the different calculation methods both standards present a comfort zone divided into two seasons: the naturally ventilated (or "free-running") and the heated or cooled season. During the naturally ventilated season the comfort zone's pattern is inclined whilst the heated or cooled season presents a flat profile. Note in Figure 1 the similarity of the resulted formulae. (For more detailed description see Humphreys et al 2010, Nicol & Humphreys 2010, and De dear 2011).

3 HYPOTHESIS

This paper works on two hypotheses valid only for naturally ventilated buildings, in which indoor environment is influenced by outdoor climate:

1. Since seasonal changes are fluid and do not suffer abrupt changes it is probable that a curve would be more adequate to represent the comfort function than the two lines model of both existing adaptive comfort models.
2. As stated by the adaptive theory, people tend to adapt their comfort expectations according to given conditions. Therefore, it is sensible to believe that people in different climate types present different comfort patterns.

4 METHODS

The proof of the first hypothesis begins with analysis of the RP-884 database.

This database is available online in a group of separated files classified in many categories such as: location, building type, year and climate type. The given climate classification was substituted by the more widespread Köppen-Geiger classification. Moreover only the major climate groups were used and the cold climates were put together resulting in:

A- humid-hot
B- arid-hot
C- temperate
D- cold

The aim of this paper is to evaluate the comfort patterns of users who are used to adapt themselves dynamically to climate variations, hence only the data from naturally ventilated buildings were considered. This explains the absence of the D category in the experiment, as none of the buildings in research projects located in the cold zone (D) were naturally ventilated.

Each file in the raw data represents a large amount of parameters, and the most important were: user's comfort vote (in a 7-point scale ranging from -3 "too cold" to +3 "too hot"), indoors temperature (real time), outdoor temperature (day mean) and air speed.

To find the comfort temperature only the votes between -1 and +1 were considered and represented in combination with the indoor temperature in which they were applied. The represented indoor temperature is an adjusted operative temperature, which is the given operative temperature, after the influence of air speed upon comfort sensation has been reduced. This reduction is described in the following formula (EN 15251).

$$\theta_{in} = \theta_i - \left(7 - \frac{50}{4 + 10 * V}\right) \quad (1)$$

For V>0,5 m/s

V=Air speed, θ_{in}=adjusted indoor temperatur, θ_i=measured operative Temperatur (raw database)

The comfort temperature is commonly represented at the y-axis.

The x-axis is used to represent the outdoor temperature. In this case, it is based upon the rounded mean outdoor temperature recorded on the raw file. The rounding helped to cluster the comfort votes in 1K intervals and to form a grid. Thereby it is possible to define, for each outdoor temperature value, the mean comfort vote and the standard deviation.

Subsequently, as shown in Figure 2, the mean comfort curve is calculated as a polynomial regression upon the mean comfort votes. The mean standard deviation is used to define the comfort range, i. e. the comfort limits above and below the mean comfort curves.

An enhancement (Dietrich 2010) was the substitution of the polynomial functions by Arc Tan functions. It came to be very useful since, unlike the polynomial functions, which started to change the direction as the local maximum and local minimum are achieved, the Arc Tan curves just change the direction twice.

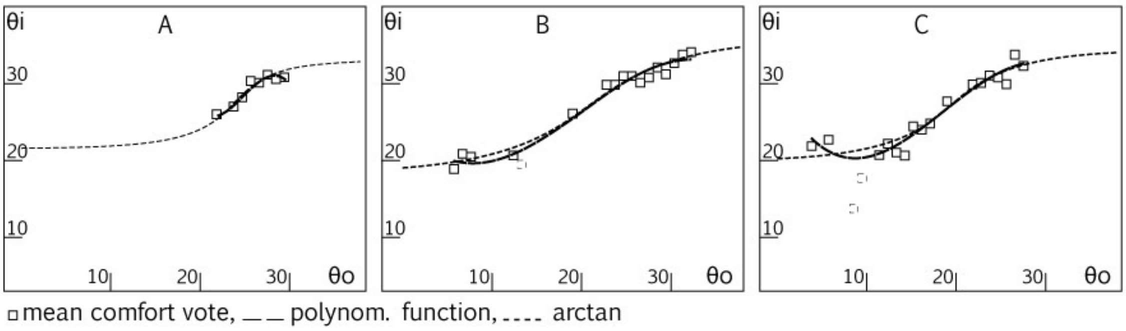

Fig. 2 - The different patterns for the three main climate groups: A, B, C.

The resulted formulae for A:

$$\theta_i = -0{,}0239\theta_o^3 + 1{,}8668\theta_o^2 - 47{,}529\theta_o + 421{,}34 \quad (2)$$

$$\theta_i = 26{,}5 + \left(-\frac{9}{\pi * \arctan[0{,}37 * (\theta_o - 25{,}7)]}\right) \quad (3)$$

The resulted formulae for B:

$$\theta_i = -0{,}0014\theta_o^3 + 0{,}0911\theta_o^2 - 1{,}2127\theta_o + 23{,}316 \quad (4)$$

$$\theta_i = 25{,}25 + \left(-\frac{17{,}5}{\pi * \arctan\left[0{,}15 * (\theta_o - 21{,}7)\right]} \right) \quad (5)$$

The resulted formulae for C:

$$\theta_i = -0{,}0024\ \theta_o^3 + 0{,}1393\ \theta_o^2 - 1{,}9593\ \theta_o + 27{,}392 \quad (6)$$

$$\theta_i = 26 + \left(-\frac{14}{\pi * \arctan\left\{0{,}18 * \left[0{,}19 * \left(\theta_o - 20{,}4\right)\right]\right\}} \right) \quad (7)$$

Where: θ_i= comfort temperature, θ_o=mean outdoor temperature.

5 DISCUSSION

After the comfort limits for the three different climate groups have been defined as shown before, they can be used for an evaluation of the thermal performance during the design process. This process is presented schematically in Figure 3 and will be described in the following.

The first step would be the climate classification itself into the climate groups A, B, C or D (Fig. 3, #1). The second step is the linkage between climate and the basic design statements. These design statements refer to the Mahoney tables (Königsberger et al 1971) and to Eproklid (de Siqueira 2010). The direct linkage to the different climate zones has been described less explicitly than in the Mahoney tables, however it is adequate for its present purpose, being only a quick start-up for further optimization. (Fig. 3, #2)

Subsequently the indicted design strategies are related to appropriate passive conditioning strategies as shown by Givoni (1998) (Fig. 3, #3).

At this point follows the first evaluation due to a thermal simulation combined with the proposed comfort limits discussed in paragraph 4. (This simulation requires detailed definitions of parameters such as air change ratio, internal gains, user's profile etc., which could be object of another research.) If the result of this evaluation turns out as "hot" or "cold", either the available design and the passive strategies can be optimized, or, if necessary, one of the low energy conditioning strategies introduced by Givoni (2011) can be applied (Fig. 3, #4).

If the next evaluation shows that the comfort state can be achieved by no means, an active conditioning strategy has to be chosen (Fig. 3, #5).

In the following the process itself will be described for each of the three climate groups.

As the outdoor climate in the A-group (humid-hot) usually stays close to acceptable comfort limits it is basically necessary to prevent extra thermal stresses. Therefore sun protection and light materials are used to avoid thermal loads. The large opening ratio required allows permanent cross ventilation as a passive conditioning strategy. Those recommendations guarantee the enhancement of the comfort. If necessary, an indirect evaporative system can be used as low energy conditioning. Givoni and Gonzales showed positive results in an experiment in Maracaibo, Venezuela in these climatic conditions (Givoni 2011).

For the B-group (arid-hot), as both annual and daily swings are usually large, it is reasonable to combine high thermal mass with good sun and wind regulation. In the cold season sun radiation is allowed to warm up indoors and daytime ventilation is preferred, whilst in the hot season sun radiation should be completely avoided and nocturnal ventilation prevails. These passive conditioning strategies could be complemented with direct or indirect evaporative cooling systems, if comfort state cannot be achieved in the hot season.

For the C-group usually similar strategies as for the B-Group can be applied except that more thermal insulation and less thermal mass are needed mainly in the coldest zones of this climate type.

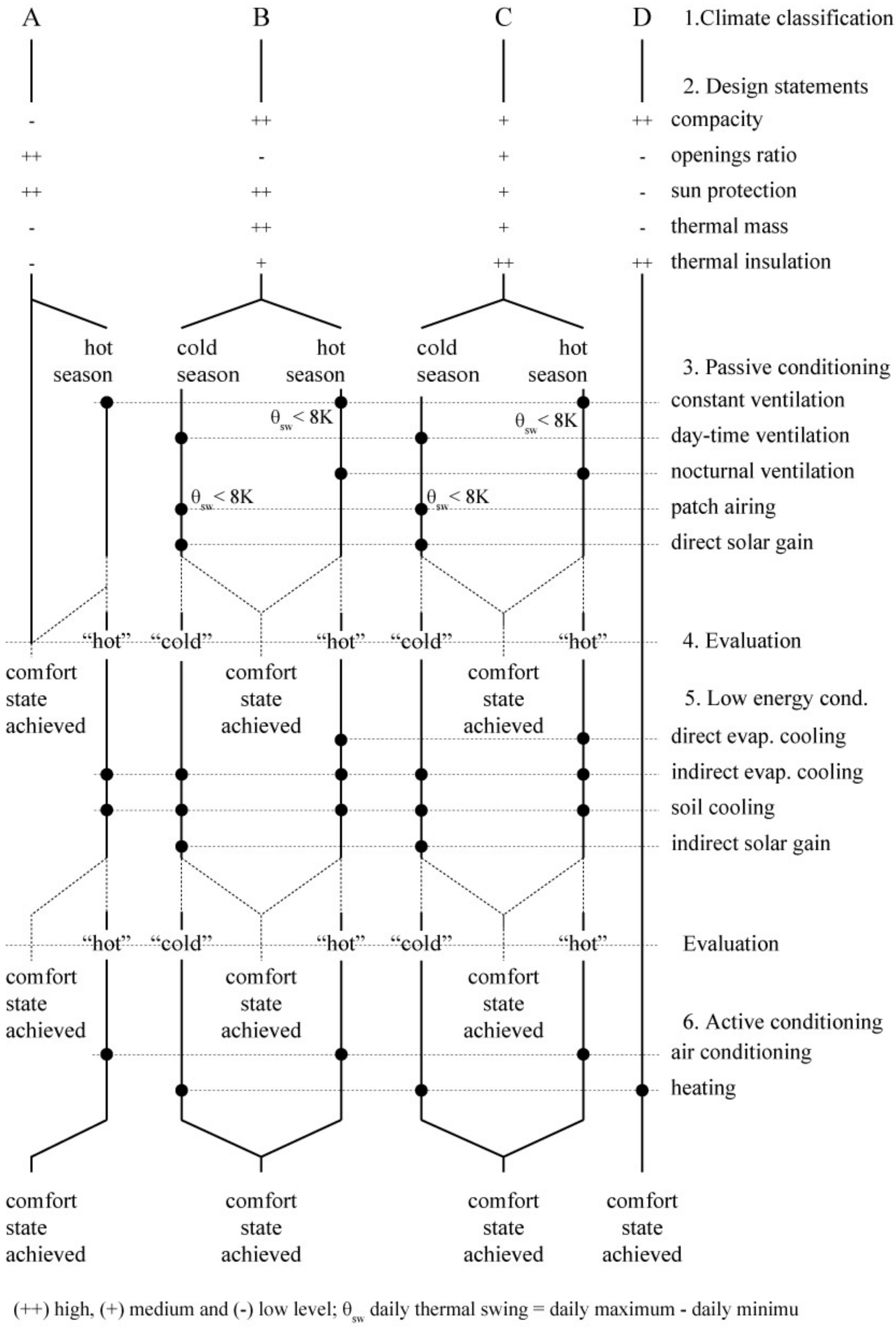

Fig. 3 - Schematic presentation of the design process using proposed comfort limits

6 CONCLUSIONS

The paper presents some evidence that support both hypotheses.

Firstly, since all the functions show high level of confidence (r^2>0.9), it can be stated that a curve is suitable to describe a comfort function.

Secondly, as the pattern's differences between the three curves are remarkable, the paper's second hypothesis is also verified. Note in Figure 4 that the A-function is very short and inclined whilst the B-function is both longer and flatter.

Moreover, it has been shown that by using the proposed climate comfort limits an effective and practical design-tool can be created, which here has only been explained schematically. The detailed description of this design-tool could be subject for a further research.

Two points are still unclear:

1. The adopted comfort ranges are compromising: 1.5K (A), 3K (B) and 2.7K (C). De Dear (2011) shows how to quantify the enhancement of comfort limits due to elevation of air speed. It is arguable though, if the comfort ranges are constant parallel to the mean comfort.

2. As the RP-884 is focused on surveys in office buildings, it is desirable to investigate if the patterns originated in other functions e.g. dwellings would diverge.

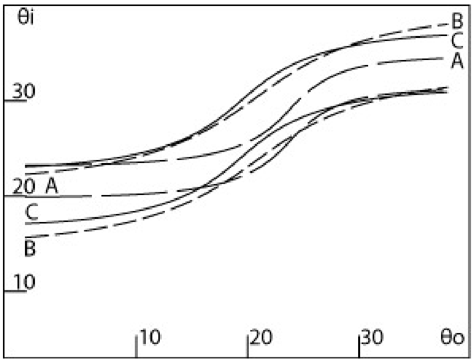

Fig. 4 - The Arc tan curves overlay for comparison of those patterns

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The Primary Energy Factors play a central role in European 2020 targets achievement

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ABSTRACT: The primary energy factors are numerical coefficients that weigh the different energy carriers, comparing them to the corresponding energy sources. The 2010/31/EU Directive establishes that the building energy performance should be expressed by a primary energy index. The analysis of the values currently employed in the European Countries shows that the performance assessment results are highly dependent from these values. The aim of the paper is to show that primary energy factors can play a central role for leading the building sector towards the European 2020 targets achievement. Starting from their determination it is possible to direct the choice among different energy carriers, as well as to rule the competition between renewable and fossil energy sources. Moreover the PEF values diversification for the imported or exported energy allows to advantage the distributed generation compared with the power generation, and the on-site produced energy consume compared with the input to grid.

1 INTRODUCTION

The “20-20-20” strategy for smart, sustainable and inclusive growth defines the energy and environmental targets that the European Union is committed to achieve by 2020 (EC 2012). The targets are: a 20% reduction of EU greenhouse gases emissions compared to the 1990 levels; the reaching of a 20% share of EU gross final energy consumption supplied from renewable energy sources; a 20% improvement in the EU energy efficiency through a 20% reduction of primary energy consumption. The Eurostat statistical data currently available (Eurostat 2012) indicate that in 2010 the levels reached for the three targets are respectively 15.0%, 12.5%, 5.4%. The target of a 20% reduction of primary energy consumption is the most far from reach.

The building sector accounts for 40% of total energy consumption in the European Union (EEA 2012). So the 2020 targets achievement is directly dependent on the energy efficiency efforts in this sector. The energy saving potential to 2020 is 27% for the residential building sector and 30% for the services building sector (European Commission 2006). The CO_2 emission reduction potential for the residential and services building sector is 20% in the reference scenario and 25% in the alternative efficient technology scenarios (European Commission 2011a). In 2010 the EPBD Directive (European Union 2002) has been recasted, in order to lead the building sector toward European 2020 targets achievement. The EPBD recast Directive (European Union 2010) establishes that the building energy performance should be expressed by a primary energy index based on Primary Energy Factors (PEF) per energy carrier, which can be derived from national or regional annual average.

The aim of the paper is to show that the PEF can play a central role for leading the building sector towards the European 2020 targets achievement. The results of the building energy performance assessment are directly dependent on the PEF values. Therefore they can direct the choices among different energy carriers used to meet the building energy needs.

2 RELATION BETWEEN PRIMARY ENERGY FACTORS AND ENERGY PERFORMANCE

2.1 *Energy Performance*

According to EN/TR 15615 (CEN 2008), the energy performance of a building is the sum of the weighted net delivered energy used to meet the building energy needs. The building energy performance assessment has a double purpose. The first is to check the minimal energy performance requirements for the new and existing buildings. The second is to express through an energy certificate the building energy value. The energy certification can be related to the energy classification. The energy certification and the energy classification should drive the real estate market, attributing a higher economic value to those building which have a higher energy performance. Currently the real estate market pushes towards high energy performance buildings. The higher prices of sale or rent allow to compensate the higher construction/refurbishment initial investment costs, compared to the Building As Usual prices and costs, and make suitable push the building energy performance beyond the minimal requirements.

Currently in European Countries three different indices are employed in the building energy performance assessment: primary energy, CO_2 emissions, final energy (EPBD-CA 2010). If the final energy index is employed, the building energy performance depends only on the building features. If the primary energy index or the CO_2 emission index is employed, the building energy performance depends also on the conversion or emission factors values. The primary energy index is already employed in most Member States, and its employment is expected also in the Countries where is not yet applied, in compliance with the EPBD recast Directive.

In the real estate market the economic value of a building increases when its energy performance increases. At the same building energy needs, the energy performance of a building increases when the PEF values decrease. The purpose of the PEF is to weigh the energy carriers. The PEF are able to direct the choices among different energy carriers because, at the same building energy efficiency and initial investment costs, the energy and economic overall building value depends on their values.

2.2 *Primary Energy Factors*

According to EN/TR 15615 (CEN 2008), the primary energy is defined as energy that has not been subjected to any conversion or transformation process. For example the fossil fuels. The secondary energy originates from the primary energy, through conversion or transformation processes. For example the electricity. The purpose of the PEF is to weigh the energy carriers, comparing them to the corresponding energy sources. The PEF are numerical coefficients determined as the inverse of the ratio between one unit of energy delivered to the building and n units of primary energy expended to deliver it. The PEF take into account the energy expenditure for energy carriers distribution and transmission, and also it take into account the efficiency of conversion or transformation processes from primary to secondary energy. So, employing the primary energy index, the energy performance of a building depends not only on the building features, but also on the energy supply chain features.

Currently in the European Union a shared methodology for the PEF values calculation lacks. An average European reference value of the electricity PEF, 2.50, is given in the 2006/32/EC Directive (European Union 2006). The PEF calculation is carried out at national or regional level, according to technical or political criteria. If technical criteria are employed, the PEF values are dependent on the energy supply chain efficiency, and are derived from the ratio between final energy consumption and primary energy consumption. An example of technical PEF value calculation is described in a report published by the Sustainable Energy Authority of Ireland (SEAI 2012). If political criteria are employed, the PEF values are dependent on the national or regional energy policy, which advantages some energy carriers and disadvantages others.

In the following paragraphs is shown that in the building sector the PEF can direct the choices among different energy carriers: 1) the choice among different fossil fuels; 2) the choice between fossil fuels and electricity; 3) the choice between fossil fuels and renewable fuels. Furthermore the PEF can direct the choices on electricity: 1) the choice between power generation and on-site generation; 2) the choice between consumption and input in grid of the electricity produced from on-site generation.

3 ROLE OF THE PEF IN BUILDING SECTOR RELATED TO THE CHOICE AMONG DIFFERENT ENERGY CARRIERS

3.1 *Choice among different fossil fuels and between fossil fuels and electricity*

The European decarbonisation energy roadmap is based on three different strategies (European Commission 2011b): energy end-uses electrification; increase in the renewable energy source share in the electricity power generation; CO_2 capture and storage. The building sector is directly involved from the first strategy and indirectly involved from the second strategy. The "Odyssee" report on the energy efficiency indicators in Europe (Odyssee 2012) shows that currently the European energy end-uses are supplied for 25% from electricity and for 57% from fossil fuels in the household building sector, and for 43% and for 48% respectively in the tertiary building sector. The share of fossil fuels is composed for 68% from gas and for 26% from oil in the household sector, and for 68% and for 29% respectively in the tertiary sector. There are different strategies for leading the building sector towards the CO_2 emissions reduction. One is the fuel switching from oil to gas. Another is the fuel switching from fossil fuels to electricity.

According to Sustainable Energy Action Plan "SEAP" data (SEAP 2012), the gas has a lower CO_2 emission factor than the oil. The energy efficiency of a fuel fired boiler is approximately equal if it is fuelled from gas or oil. At the same building energy needs, a lower PEF value for the gas rather than the oil leads to a higher building energy performance if a gas-fired boiler is used. In this case the PEF values are able to direct the choice towards that fuel which has lower CO_2 emission factor. The PEF values, indicated as $f_{P,x}$, currently employed for fossil fuels in several European Countries are given in (Sartori et. al. (in press)). In some Countries, as in Spain, they are different for gas and oil, respectively 1.07 and 1.12. In other, as in Germany, they are equal for all fossil fuels, 1.10. In the Countries where different PEF values are employed, the differentiation facilitates the fuel switching from oil to gas and leads towards CO_2 emissions reduction.

According to "SEAP", the electricity has a higher CO_2 emission factor than the fossil fuels. However the electricity is a suitable energy carrier, because the positive impact due to the high energy end-uses efficiency is greater than the negative impact due to the high CO_2 emission factor. Currently the average European renewable energy source share in the electricity power generation is 19.0% (European Commission 2009). The trends show that in 2020 it will be 32.6%. So progressively the electricity suitability among different energy carriers will increase because the electricity CO_2 emission factor will decrease, instead the fossil fuels CO_2 emission factors will remain unchanged.

The heating energy use is the main energy end-use in the building sector (Odyssee 2012). The heat pump technology is more efficient than the fuel fired boiler technology to fuel the heating plants. The efficiency is defined as the ratio between thermal energy delivered to the building and energy carriers expended to deliver it. The RES Directive (European Union 2009) establishes that the aerothermal, idrothermal and geothermal energy are renewable energy sources. The fuel switching from fossil fuels to electricity leads towards CO_2 emissions reduction, end-uses efficiency increase and renewable share increase in gross final energy consumption.

At the same building energy needs, applying the primary energy index, the energy performance of a building depends on the heating plant fuelling technology efficiency and on the PEF values of the energy carriers used to fuel it. The heat pump technology is suitable if the ratio between the Coefficient Of Performance (COP) and the boiler efficiency is greater than the ratio between $f_{P,el}$ and $f_{P,x}$. The RES Directive establishes that should be take into account only those heat pumps which have a high efficiency compared to the primary energy consumption. That is in the case of electric heat pumps, only those which have a high COP compared to the electricity PEF value. The PEF values, indicated as $f_{P,el}$, currently employed for electricity in several European Countries are given in (Sartori et. al. (in press)). We calculated the ratio between $f_{P,el}$ and $f_{P,x}$ for gas, based on these PEF values. The results are given in Figure 1. The PEF values employed in Austria have the smallest ratio, 1.70, and the PEF values employed in Germany have the largest ratio, 2.72. If this ratio decreases, the heat pump technology suitability increases. According to the Ecofys PEF report (Molenbroek et al. 2011), the increase of the average European renewable energy source share in the electricity power generation will change the average European electricity PEF from the current value, 2.50, to the expected value, 2.00, in 2020. So progressively the electricity suitability among different energy carriers will increase.

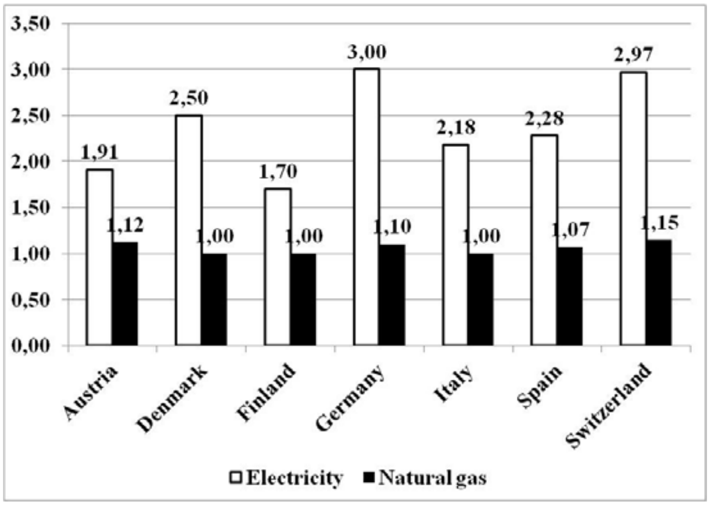

Figure 1. Ratio between $f_{P,el}$ and $f_{P,x}$ in several European Countries.

3.2 *Case-study*

We applied to a case-study the topics described in the previous paragraph.

We modeled a single family residential building (two floor dwelling) through an hourly numerical simulation, assuming a conventional user profile and a weather profile from Test Reference Year (Florence – Italy). The main building data are given in Table 1. The heating plant maintains the indoor temperature at 20 °C setpoint during the winter season (1 November – 15 April). The heating seasonal thermal energy need is 23,750 kWh, calculated downstream of the thermal generation system.

Table 1. Data for the case study building.

Conditioned area	200	m^2
Conditioned volume	800	m^3
Shape factor	0.45	
Wall mean U-value	1.5	W/m^2K
Window mean U-value	3.0	W/m^2K
Glazing factor	0.15	

We modeled three different thermal generation systems which fuel the heating plant: the first is an oil-fired boiler, which has 0.95 average seasonal efficiency; the second is a gas-fired boiler, which has 0.95 average seasonal efficiency; the third is an electric air heat pump, which has 3.50 average seasonal COP. The energy carriers expenditure is: 1956 kg of oil, 1908 kg of gas and 6785 kWh of electricity. The lower heating values, derived from the 2006/32/EC Directive (European Commission 2006), are 12.778 kWh/kg for oil and 13.10 kWh/kg for gas. The CO_2 emission factors, derived from (SEAP 2012), are 0.267 kg(CO_2)/kWh for oil, 0.202 kg(CO_2)/kWh for gas, and 0.46 kg(CO_2)/kWh for electricity.

For the three systems we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in Italy, Switzerland and Austria, derived from (Sartori et. al. (in press)). The results are given in Table 2.

Table 2. Energy Performance and CO_2 emissions for the case study building.

Reference	Oil fired boiler		Gas fired boiler		Electric air heat pump	
	PEF	Pr. En. Index kWh/m²anno	PEF	Pr. En. index kWh/m²anno	PEF	Pr. En. Index kWh/m²anno
Italy	1	131.6	1	131.6	2.18	77.9
Switzerland	1.15	151.3	1.24	163.2	2.97	106.1
Austria	1.12	147.4	1.13	148.7	1.91	68.2
emissions kg(CO_2)		6675		5050		3121

The calculation results explain the topics described in the previous paragraph.

The overall building CO_2 emissions are lower if the gas-fired boiler is used rather than if the oil-fired boiler is used (-24%). If the PEF values for gas and oil are equal, as in Italy, also the building energy performance is equal. In this case the PEF are unable to direct the choice among different fuels. Instead if the PEF value for gas is lower than for oil, as in Switzerland, the building energy performance is higher if gas is used than if oil is used. In this case the PEF are able to direct the choice towards that fuel which causes lower overall building CO_2 emissions.

The overall building CO_2 emissions are lower if the electric heat pump is used than if fuel fired boiler is used (-53% and -38%). Moreover the heat pump allows a higher end-uses efficiency and an about 70% renewable share (aerothermal energy) in gross final energy consumption. The building energy performance using the heat pump is higher than using the fired boiler in all three Countries. The heat pump suitability, dependent on the PEF values, is higher in Austria, where the ratio between $f_{P,el}$ and $f_{P,x}$ for gas is 1.69, than in Switzerland, where the ratio is 2.39.

3.3 *Choice between fossil fuels and renewable fuels*

The CO_2 emitted during combustion from a wood renewable fuel, that is wood pieces or wood pellets, is equal to the CO_2 absorbed during growth from the tree from which the wood was originated. According to “SEAP” a wood fuel has a CO_2 emission factor equal to 0 if wood is harvested in a sustainable manner. The fuel switching from fossil fuels to wood fuels leads towards the CO_2 emissions reduction and the renewable share increase in gross final energy consumption. The energy efficiency of a wood fuel fired boiler is lower compared to that of a fossil fuel fired boiler, however they are approximately similar. At the same building energy needs, applying the primary energy index, the building energy performance depends on the PEF values and on the choice between total PEF and non-renewable-PEF.

According to EN/TR 15615 (CEN 2008) there are two criteria about the PEF. Non-renewable PEF, which take into account only the non-renewable part of primary energy; total PEF, which take into account also the renewable part of primary energy. A fossil fuel has the total PEF value equal to the non-renewable PEF value. A wood fuel has the total PEF value equal to the sum of the non-renewable PEF value and 1. 1 is the PEF value conventionally attributed to the renewable energy sources. The PEF values currently employed for wood fuels in several European Countries are given in (Sartori et. al. (in press)). In some Countries, as in Sweden, the wood fuels total PEF values are equal to the fossil fuels total PEF values, 1.20. In others, as in Germany, they are similar, respectively 1.10 for fossil fuels and 1.20 for wood fuels.

If the primary energy index is calculated applying the total PEF, the energy performance of a building heated from a wood fuel fired boiler is approximately similar to that of a building heated from a fossil fuel fired boiler. The small EP differences possibly resulting from different heating-fuels are due to small energy efficiency differences of boilers and/or to small total PEF values differences. In this case the PEF are unable to direct the choice among different fuels. Instead if the primary energy index is calculated applying the non-renewable PEF, the energy performance of a building heated from a wood fuel fired boiler is higher to that of a building heated from a fossil fuel fired boiler. In this case the PEF are able to direct the choice towards that fuel which allows a lower CO_2 emission and a higher renewable share in gross final energy consumption.

3.4 *Case-study*

We applied to the previous case-study the topics described in the previous paragraph.

We modeled two different thermal generation systems which fuel the heating plant: the first is a wood pieces fired boiler, which has 0.90 average seasonal efficiency; the second is a gas fired boiler, which has 0.95 average seasonal efficiency. The energy carriers expenditure is: 5654 kg of wood pieces and 1908 kg of gas. The lower heating values, derived from the 2006/32/EC Directive (European Commission 2006), are 4.667 kWh/kg for wood pieces and 13.10 kWh/kg for gas. The CO_2 emission factors, derived from “SEAP”, are 0 kg(CO_2)/kg for wood pieces and 0,202 kg(CO_2)/kWh for gas.

For the two systems we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in Austria and Germany, derived from (Sartori et. al. (in press)). The results are given in Table 3.

Table 3. Energy Performance and CO_2 emissions for the case study building.

Reference	Wood pieces fired boiler		Gas fired boiler	
	PEF	Pr. En. index kWh/m²anno	PEF	Pr. En. index kWh/m²anno
PEF total, Germany	1.20	166.7	1.10	144.7
PEF non-ren., Germany	0.20	27.8	1.10	144.7
PEF total, Austria	1.01	140.3	1.12	147.4
PEF non-ren. Austria	0.01	1.4	1.12	147.4
emissions kg(CO_2)		0		5050

The calculation results explain the topics described in the previous paragraph.

The building overall CO_2 emissions are 0 if wood pieces boiler is used. Moreover the wood pieces fired boiler allows a very high renewable share in gross final energy consumption. If the primary energy index is calculated applying the total PEF, the building energy performance when the heating plant is fuelled from the wood pieces fired boiler is approximately similar to the one when it is fuelled from the gas fired boiler. In this case the PEF are unable to direct the choice among different fuels. If the primary energy index is calculated applying the non-renewable PEF, the building energy performance when the heating plant is fuelled from the wood pieces fired boiler is much higher than when it is fuelled from the gas fired boiler. In this case the PEF are able to direct the choice towards that fuel, wood pieces, which causes lower overall building CO_2 emissions and allows a very high renewable share in gross final energy consumption. These results occur both for the Austrian PEF and for Germany PEF.

4 ROLE OF THE PEF IN BUILDING SECTOR RELATED TO THE CHOICE ABOUT THE ELECTRICAL ENERGY CARRIER

4.1 *Choice between power generation and on-site generation and between consume and input in the grid*

An on-grid building interacts with the electric grid through the system boundary. If there are on-site electric generation devices based on renewable energy sources, as the sun or the wind, the building imports electricity from power generation and exports electricity from on-site generation. The on-site generation based on renewable energy sources contributes to reach the 2020 target of a 20% renewable share in gross final energy consumption. The grid electricity PEF value affects the competition between power generation and on-site generation. At the same building electric energy need, a high grid electricity PEF value pushes towards the installation of on-site electric generation devices. Instead a low grid electricity PEF value pushes towards the electric taking from the grid.

The mismatch between users consumption profiles and on-site generation profiles makes necessary to take electricity from the grid when the on-site generation is smaller than the users consumption and to input electricity in grid when the users consumption is larger than the on-site generation. The on-site generated electricity amount consumed from the users is deducted from the grid electricity amount taken from the grid. The deduction implicitly affects the building energy performance assessment because in this case the on-site generated electricity has virtually the same PEF value of the grid electricity.

If the PEF values for the imported and exported energy are equal, the users consumption and the input in grid affect the building energy performance assessment in the same way. If the PEF value for the delivered electricity is higher than the one for exported electricity, the users consumption is advantaged compared to the input in grid, because the amount of on-site generation that is input in grid affects the building energy performance assessment less than the one that is consumed. Instead if the PEF value for the delivered electricity is lower than the one for imported electricity, the input in grid is advantaged compared to the users consumption, because the amount of on-site generation that is consumed affects the building energy performance assessment more than the one that is input in grid.

4.2 *Case study*

We applied to a case-study the topics described in the previous paragraph.

We modeled a single family residential building (two floor dwelling) through an hourly numerical simulation, assuming a conventional user profile and a weather profile from Test Reference Year (Florence – Italy). The building main data are equal to the previous case-study. The heating plant maintains the indoor temperature at 20 °C setpoint during the winter season (1 November – 15 April) and the cooling plant maintains the indoor temperature at 26 °C setpoint during the summer season (1 June – 31 August). The seasonal thermal energy needs are 23,750 kWh for heating and 12,250 kWh for cooling, calculated downstream of the thermal generation system. The heating and cooling plants are fueled from an electric air heat pump, which has average seasonal COP 3.50 and average seasonal Energy Efficiency Ratio (EER) 2.50. The seasonal building electric energy needs are 6785 kWh for heating and 4900 kWh for cooling, calculated upstream of the thermal generation system.

We modeled also a photovoltaic system integrated on the building roof (Building Integrated Photo Voltaic – BIPV) composed of polycrystalline silicon modules. The BIPV system features are: surface 90 m^2; electric peak power 9 kW_p; annual overall producibility 9933 kWh. The BIPV system production is used to fuel the heat pump during the heating and cooling seasons, and is input in grid otherwise.

We simulated two different configurations of the BIPV system. The first without on-site electric storage devices: in this case the amounts of delivered and exported energy depend only on the users consumption profile and on the on-site generation profile. The second with on-site electric storage devices: in this case the amounts of delivered and exported energy depend also on the storage devices capacity. The energy amounts for the two configuration with BIPV and for that one without BIPV are given in Table 4.

For the two configuration with BIPV and for the one without BIPV we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in the Netherland, where the PEF value for exported energy, 2.00, is lower than that the one for the delivered energy, 2.56, and in United Kingdom, where the PEF value for exported and delivered energy are equal, 2.92, derived from (Sartori et. al. (in press)). The results are given in Table 5. The CO_2 emission factors are 0,46 kg(CO_2)/kWh for the delivered electricity, derived from “SEAP”, and 0 kg(CO_2)/kWh for the exported electricity, because it is produced from devices based on renewable energy sources, namely the sun.

Table 4. Energy amounts for the case study building.

System	Without BIPV	With BIPV without storage	With BIPV with storage
	kWh	kWh	kWh
Delivered energy	11.685	8107	4529
Exported energy	0	6356	2778
Consumed energy	11.685	11.685	11.685
Produced energy	0	9934	9934

Table 5. Energy Performance and CO_2 emissions for the case study building.

Reference	Without BIPV	With BIPV without storage	With BIPV with storage
	Pr. En. Index kWh/m^2anno	Pr. En. index kWh/m^2anno	Pr. En. Index kWh/m^2anno
PEF the Netherland	149.57	40.21	30.19
PEF United Kingdom	170.6	25.56	25.56
emissions kg(CO_2)	5375	3729	2083

The calculation results explain the topics described in the previous paragraph.

If the PEF values for the imported and exported energy are equal, as in United Kingdom, the energy performance results are equal in both BIPV system configuration. If the PEF value for delivered electricity is higher than the one for exported electricity, as in the Netherland, the energy performance in the configuration with storage is higher than in the one without storage (+25%). In this case the users consumption is advantaged compared to the input in grid, and the PEF values lead towards the configuration which has the lower overall building CO_2 emissions.

5 CONCLUSIONS

The topics discussed in the paper show that the primary energy factors can play a central role for leading the building sector towards the European 2020 targets achievement. The PEF are a very important means for the energy policy in the building sector at national or regional level. They are able to direct the choice among different energy carriers used to meet the building energy needs, because the building energy performance assessment results depend directly on their values. The cases-study show that the PEF can lead to CO_2 emission reduction, end-uses energy efficiency increase and renewable share increase in gross final energy consumption.

An overall European energy policy strategy about the PEF lacks. This is a missed opportunity to make the PEF a central element in “20-20-20” strategy. However the PEF values currently employed in some European Countries are already suitable for leading the building sector towards the European 2020 targets achievement. Instead those currently employed in other should be redetermined, according to technical or political criteria, in order to facilitate the fuel switching from oil to gas, from fossil fuels to electricity and from fossil fuels to renewable fuels. Alternatively should be established a shared methodology for the PEF values calculation, so as to obtain an overall effective impact at European level.

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Sustainability in construction, between politics and economics. A comparison of the U.S. market and the Italian one.

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ABSTRACT: The requirement of sustainable buildings is more and more clearly communicated and perceived. The manufacturers of materials and components for the building certify the characteristics of what we trade, and there are specific certifications for buildings and processes of design and construction. In this way, and thanks to some government incentives, the need for sustainability becomes a demand. Recently this mechanism of demand and supply can also find a translation in terms of economic forecasting. Some markets are more mature and more time are attentive to the need for sustainability of buildings. Other markets are slower or more complicated, and therefore only recently and only with numerous approximations can be studied from the point of view of sustainability. The U.S. market belongs to the first category (it is influenced by the LEED certification for some time), the Italian market belongs to the second category (it is characterized by a large and old building heritage). Despite the economic crisis, it is possible to study the performance of the U.S. market and see how it is positively influenced by the sustainability certification of buildings. A similar study can be done for the Italian market: some benefits can be found by improving the energy efficiency of buildings, other benefits may be determined by policies that bring results in the medium and long term.

1 INTRODUCTION

This paper is not aimed at developing the definition of sustainability of buildings and do not want to propose design solutions for achieving energy efficiency or to reduce the environmental impact of buildings. This paper proposes an analysis of market demand (this also means a reading of user needs) and displays the data currently available to interpret the development of the construction industry. The focus is placed on the European market and, in particular, the Italian one, this analysis is carried out by comparison with the U.S. market, which, in some respects, is more advanced in considering the value of sustainability of the built environment.

2 THE ITALIAN REAL ESTATE INDUSTRY

2.1 *The data that describes the current state*

The estimates proposed by "Scenari Immobiliari" show that in 2020 the Italian real estate industry could charge about € 180 billion, this would mean an increase of 62% compared to 2011.

"Scenari Immobiliari" is an independent research Institute, it analyses the property markets and, in general, the economy of the territory in Italy and Europe. "Scenari Immobiliari" emphasizes that these forecasts can be confirmed only if measures are taken to ensure easier access to credit, only under this condition could be carried out investments for the construction of new buildings and the renovation of existing buildings.

The most interesting aspect of this study is that the quantitative growth will be accompanied by a qualitative growth of the real estate. This is because sustainability can be considered one of the parameters which define the quality of the built environment.

An interesting fact to understand the changes in the volume of business in the construction industry is related to the big investors, they will increase investment by about 50% compared to 2011.

Even indirect investments play an increasing role and economic growth in Italy is expected to be supported once again by the residential sector. As in the rest of the world, even in Italy, the residential sector will be structurally modified by demographic trends and the needs of users, which are set by market demand.

In large cities the pressure of this demand will be greater and, given the increase in population and the current period of crisis, the demand will grow in particularly in two fields: low-cost homes will grow (these houses will be allocated to needy people, such as immigrants but not only) and properties suitable for the life of the elderly (because in Italy the rate of aging of the population is very high).

“Scenari Immobiliari” explains that in Italy the selection of properties is deficient from a qualitative point of view but above from the point of view of quality. Studies done by “Scenari Immobiliari” shows how the demand for homes will be organized regarding to three category of wealth (high, medium and low).

In Italy there are demographic changes. These are related to of the sons stay at home related to living with elderly parents (or grandparents) and linked to the increasing presence of immigrant families (which usually have more children than families of Italian origin). These changes will lead to a greater demand for larger homes, homes with suitable spaces to ensuring the privacy of each member of the family.

The families of the middle class will be able to grow in number but will be reduced from the dimensional point of view. Lone parent families will be more and this will require an adjustment of the offer which is now based on medium to large (80-120 square meters) and in the future will have to resize.

Even the families of the high category of wealth will change their demand, especially for the adoption of home automation equipment, and the ever increasing environmental awareness.

On the one hand, the size of the Italian residential projects is expected to increase, as already happens in other European countries. On the other hand will be realized even small-scale projects in existing urban and suburban areas. It will also be possible a gradual return toward the center of the cities, this will increase the prices of existing buildings and will lead to an increase in demand for restructuring (the opposite of what happens today, that is, the fall in sales of existing buildings).

“Scenari Immobiliari” also provides information about the real estate market for the service sector. The demand for traditional offices will fall and investors (including international investors) will focus their attention on spaces that have to be efficient, flexible, high-tech and sustainable. As in the rest of Europe, even in Italy the average space per worker will be reduced, this is a consequence of the need to reduce operating costs and of the increase in teleworking.

The retail will continue to be the preferred asset class by institutional investors, both Italian and foreign. Even in this sector there will be the return inwards of the city, but the average size of the projects will be lower than the European average. Another important requirement is the flexibility of the spaces both of structure and operational, with timetables and different services depending on the area and the user base. The importance of the restaurant industry will decrease. Shopping malls and outlets will increase both in number and in size, on the other hand, the e-commerce will increase and consequently the demand for spaces dedicated to the trade will decline, but this will also lead to a strong increase in demand for logistics space (these must be of small size and high technology).

The key factors determining the success of all designs will be the strategic location, energy conservation and sustainability.

Despite all these data, which are partly positive, the development of construction industry in Italy will be slower than the European average, it is expected that in 2020 the value of construction in Italy will be in 12th place in the world ranking, this is a negative compared to 7 th place in 2010.

After the Second World War, Europe was shaken by a devastating number of people in search of a roof under which to spend the night, no matter where located, constructed using any technique and essentially equipped. The solution to the housing problem was identified in the reduction of the costs of building materials, construction sites, projects and areas: everything had to be the least possible cost, it was necessary to quickly build a large number of homes. The quality of the early years of the post-war reconstruction was characterized in this way.

In Europe, after a little more than twenty years after the end of the war the housing crisis could be considered largely resolved. The idea of home, the assessment of the cost of buildings and building technologies changed again. The number of buildings does not motivate the research, policy and the work of architects, now it is another kind of quality to move the market. The house is designed as a construction useful in responding to the needs of users. As a result, the architect, has to build homes that satisfy the needs of the time and has the role of intermediary between users and the State, which processes the policies and standards for the quality of housing. Value was given to urban design, the comfort of homes (insulation) and appearance of the buildings. Planning instruments Were made and were dubbed the first standard to help ensure the quality of the built and the implementation of policies for recovery of the housing survivor (it was in most of the buildings in the heart of the city).

Today in function to keep the existing buildings are required substantial and ongoing investment, moreover the additional higher costs are to be expected when you want to ensure adequate performance to new needs, sometimes very different from those of the past. We will study the “generalized cost”' of the buildings, as the sum of the construction cost, the operating cost and other expenses necessary to ensure the quality of the buildings during the duration of their life cycle.

The designer must work considering the life cycle of buildings in relation to the generalized cost to ensure the social and economic sustainability of the built environment. In this sense, the social housing are an important case study: their maintenance and their appropriateness are important for the whole community who bears the costs and who actually can derive many benefits from settlements of quality (benefits that are not only personal but also economic and especially social).

Today, after realizing the importance of “generalized cost”, the quality of buildings is described by the term “sustainability”, a term used mainly to emphasize the need for a greater respect for the environment: it is necessary to “satisfy the needs of the present without compromising the ability of future generations to meet their own” (WCED, 1987).

This set of definitions of the quality of the buildings correspond to the cycles in the housing market described by CRESME (Center for Economic, Social and Market Research for Building and Land). The devastation of the housing caused by World War II and the reconstruction characterize the first building cycle identified by CRESME; housing boom, boom and growth of spending are the drivers of subsequent cycles until the fifth cycle (in the ‘80s), when the house also has the function of expressing social status of its owners.

The sustainability of buildings open to new scenarios and new perspectives on the construction market, this happens in adherence with the studies that the International Council for Building (CIB) was published in 1999 in the document known as CIB Agenda 21 (Agenda 21 on sustainable construction, CIB report Publication n. 237, 1999): he redevelopment of buildings for social housing cannot avoid confronting these issues and, indeed, it has to calculate benefits, both for end users of buildings both public entities are required to manage this vast (and often outdated) building stock.

2.2 *Historical perspective*

The data shown in the previous section serve to explain that sustainability is one of the characteristics that define the quality of a building. Sustainability is a new feature but the cycle of the building market characterized by this question will certainly have characteristics in common with the previous cycles, in which the quality of the built environment was characterized in a different way.

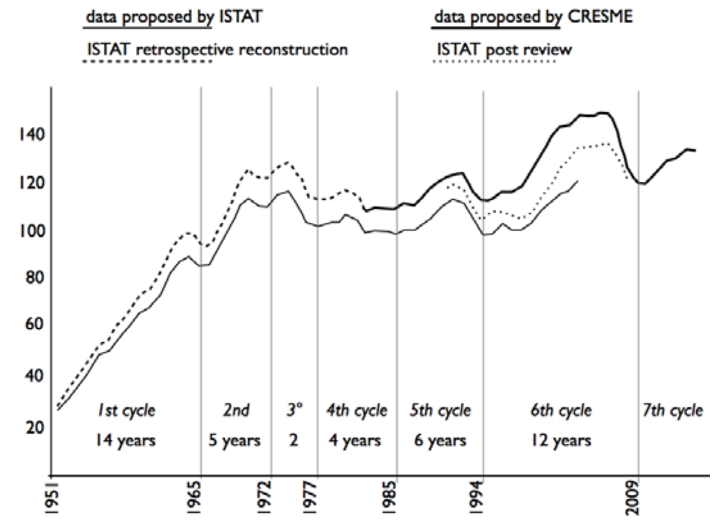

Figure 1. Cyclical series of investments in construction in Italy from 1951 to 2016 (Cresme Report, 2011).

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3 THE U.S. DATA

3.1 *Text and indenting*

Green Buildings provide financial benefits that conventional buildings do not. These benefits include energy and water savings, reduced waste, improved indoor environmental quality, greater employee comfort/productivity, reduced employee health costs and lower operations and maintenance costs. However, green building is increasingly seen as a business opportunity, client demand and market demand have become the dominant forces in the market.

The certifications are an effective way to explain the sustainability of buildings to the public and also to communicate to technicians. Moreover, the certifications are becoming more widespread, and the number the and type of certification is increasing. On these issues, the first data available are those of the U.S. market. In America, the most common certification is LEED (Leadership in Energy & Environmental Design), it is a program that provides third-party verification of green buildings.

LEED and other certifications are also widespread in Italy (and in other European countries), but certainly the most rapid and widespread dissemination can be found in America, where the LEED is a success. The reasons for this success are many: the offices have a role in image communication of the company, workers can organize class actions to raise the quality standards of the workplace (health and well-being benefits as a reason to build green), users change their homes most frequently than in Italy and so the market changes more quickly.

A market that changes faster then provides measurable data before other markets, slower. For this reason, this paper offers a quick read of data from the American market: US data can be used to predict what will happen even in countries where innovation in the construction industry is slower.

Documents published by LEED attests that total registered and certified floor area in 2009 is estimated to grow by over 40% compared to last year's totals for a cumulative total.

Furthermore the definitions and the requirements of a sustainable building continuously evolves over time, a true sustainable building typically stands the test of time because it has professional ownership and management that will normally maintain and upgrade the building keep it competitive in the market. This can be seen for residential buildings but is even more evident and important in the case of office buildings. If every building "tells" a lot about their owners, this is even more important for office buildings, buildings with which every company describes itself to the public (and to potential customers).

As a general rule, sustainable buildings attract "core" investor who tend to hold buildings over the long term. The focus is on a long-term value creation.

A study conducted by Mc-Graw-Hill Construction in 2008 shows that 70% of homebuyers are more or much more inclined to buy a green home over a conventional home in a down housing market. That number is 78% fot those earning less than \$ 50,000 per year, showing the increasing access to green buildings for all members of our society. In fact, 56% of respondents who bought green homes in 2008 earn less than \$ 75,000 per year; 29% earn less than \$ 50,000.

In the US, buildings have a lifespan of fifth to one hundred years, throughout which they continually consume energy, water, and natural resources, thereby generating significant CO2 emissions. Buildings are responsible for 39% of US CO2 emissions per year. Annually they sccount for 39% of the US primary energy use; consume 70% of US electricity; use fifteen trillion gallons of water per year; and use up to 40% of raw materials globally.

In Italy, every year, the civil sector consumed 43.6 million tons of oil equivalent (TOE), this sector was the second after the industrial consumption (which consumes 60 million TOE). The industrial consumption but also includes 5.4 million TOE for the production of building materials. The building is therefore involved in an even more important in the energy problems.

Green buildings are designed at the aim to change all these data in a more sustainable way from the point of view of the environment but also of the costs, of the consumes and of the performances. Enhanced performance for a new building cycle: the building cycle that CRESME numbers as the seventh, analyzing the Italian market (this can also be seen by comparing Figure 1 and Figure 2).

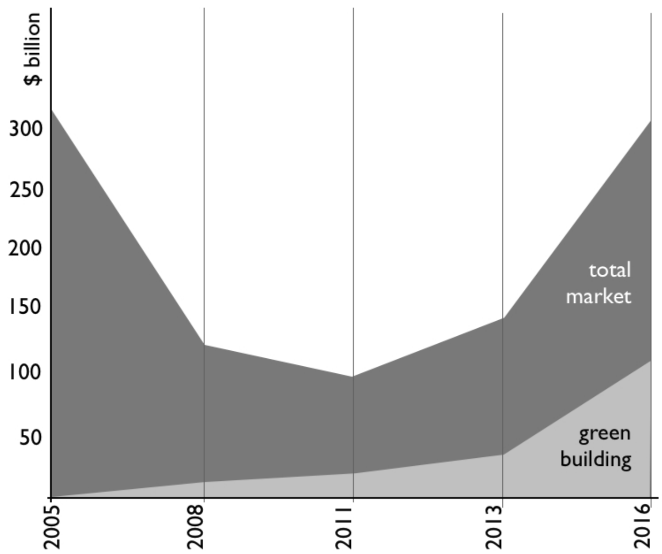


Figure 2. Green Building share of U.S. residential market, based on Mc-Graw-Hill Data.

4 SCENARIOS FOR DEVELOPMENT

4.1 *Analysis of the Italian market in comparison with the American*

Still referring to the data offered by the CRESME reasoning can be done on the Italian real estate situation, its future developments, and to answer that Italy is making on the issues of sustainability in the design.

Francesco Toso, head of market research in CRESME, has proposed a scheme that summarizes the growth sectors in decline and those of the new building cycle.

The Italian building will be driven by sustainability and probably this direction will be emphasized also by the cost of energy, a cost that continues to grow in a tangible way even in the bills paid by the users. For this reason, the energy is a cost that directs the demand towards more efficient buildings both from the point of view of energy and environmental. To date in Italy sustainable buildings are mostly experimental buildings, case studies and not clearly characterize the everyday building. The words “green”, “sustainable”, and “eco” have a great echo in the media but the terms are often used loosely and inaccurately than their real meaning. These words are often used to describe a marginal and incomplete broad themes to which they refer. Currently, in Italy, only the energy efficiency is an effective system for measuring and communication. For this reason, energy efficiency starts to be a component in the definition of the value of the property, along with location, finishes and age of the property.

The ecological culture in the Italian real estate sector spreads from small breeding ground that are beginning to develop in patchy, following the local or regional regulations. This development resembles to what happened years ago in the USA. With the development of the application greens are born of private entities that give guidance on how to build and renovate buildings. The main difference between America and Italy in America is that the spread of the idea of sustainability is driven by the market, while in Italy the regulations guiding the designers. Each strategy has pros and cons but it is impossible to deny that the construction industry, in one way or another, it is oriented towards sustainability.

Figure 3. Levels of green building activity by firms around the world, based on Mc-Graw-Hill Construction data.

5 CONCLUSIONS

5.1 *A possible plan of action*

Still The “Sectoral Innovation Watch, construction sector” developed by Europe Innova presents a framework to define the possible scenarios of development of real estate. The scenarios were developed selecting the two most relevant and most uncertain drivers: the conditions for financing on the one hand and sustainability on the other hand.

The Europe Innova explain that it was a decision by the experts that the uncertainty was seen in how sustainability is going to be achieved in the construction sector, and the quality of sustainability differs in the various scenarios.

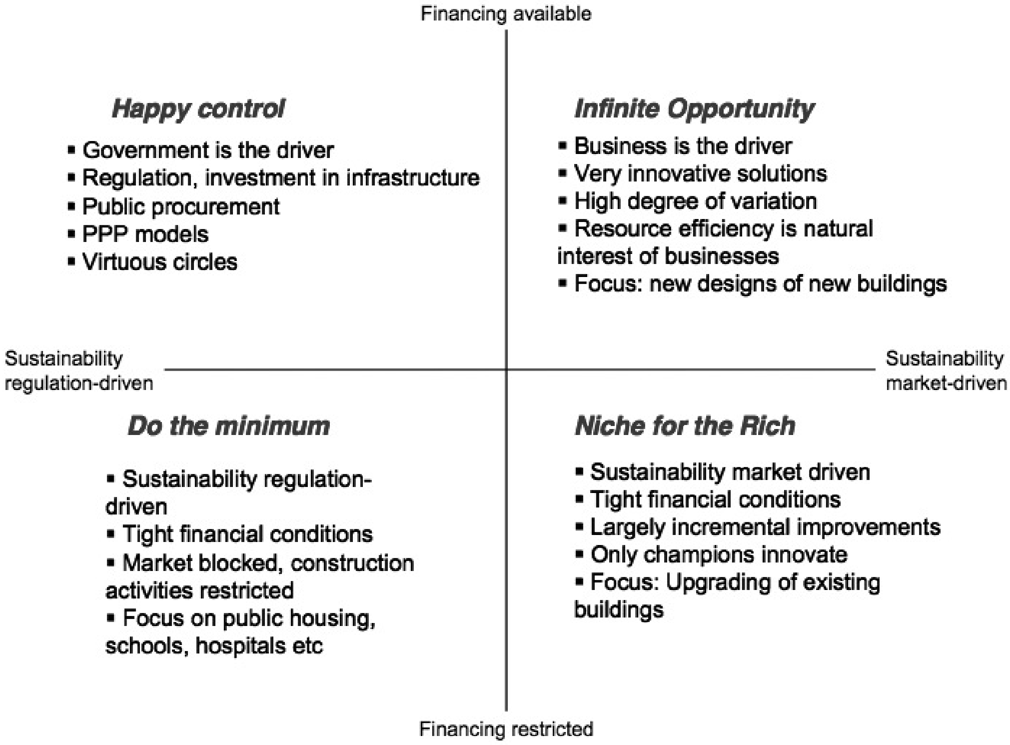
The CRESME, it was explained before, illustrates the crisis in the housing market and puts the situation in the bottom of the Cartesian plane defined by Europe Innova.

Italy is in a situation of difficult access to credit and, as seen before, the institutions are the promoters of technology investment and modernization. The market and the private sector are struggling to fit into this area. To go along the axis of economic development it is necessary a constant cooperation between research and development in both the public and private sectors, now more necessary than in any other scenario.

In order to encourage sustainability requires the exchange of ideas between users and workers in the construction industry, laws and regulations are not sufficient. If only the institutions driving the recovery of the real estate there is a risk that the policy is not up to the task, resulting in waste of resources. For clarity: if the political class is not made up of technicians in the industry, the risk would be to not be able to implement and innovate the construction industry. On the other hand, if only the market to drive sustainability, the risk is that speculation is used to increase profits.

The state should act as guarantor for the defense of the citizen against the attitudes of the speculative market, but at the same time the state should also understand and help the good innovations that the market offers. In this way there would be an increase of social capital and also the economic capital: a way to ascend the y-axis of the diagram of Europe Innova.

This will make it possible to design and build sustainable buildings, more efficient buildings, buildings that best meet the changing needs of users who are more informed and concerned about the natural environment. In this way, with new demands and new products, the housing market will recover from the crisis and the seventh round CRESME identified for Italy able to boot. This will happen for the same reasons that already today the prices of sustainable buildings made in U.S. is already growing.



Source: 1st experts' foresight workshop, Brussels, June 09.

Figure 4. The scenarios in the construction industry in Europe in the next 10-15 years according to Europe INNOVA (Loikkanen, Hyvönen, 2011).

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The Need for a Paradigm Shift in Construction Education.

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ABSTRACT: In order to ensure the success of the drive towards a sustainable economy in Ireland it is imperative that societal change occurs. This paper concentrates on the recently depleted Irish construction sector and the potential for a new direction in the industry based on a sustainable ecological approach. The following hypothesis is presented; that in order to ensure sustainable development a paradigm shift which forms the fundamental attitudes that we hold concerning the environment must take place.
This paper will look at how Education may be the entry point where attitudes can be greatly influenced in parallel with the dissemination of knowledge and skills. While outlining why the construction industry must take a lead role in the change towards a sustainable economy this paper looks at how and why the educational process itself must also change in order to embed sustainable development, its philosophy and ethos in the construction sector.

1 INTRODUCTION

To sustain the activities of production, distribution and consumption of goods and services of any economic model the resources and assets upon which it draws its real wealth need to be managed and maintained. Efficient use of materials, energy and waste is key to an efficient competitive economy. This pertains to our minerals, our fossil fuels, our forests, the air we breathe and the water we drink. Sustainable economic growth hinges on the management of these resources.

For example, even in ‘wet’ Ireland, we are inextricably linked into the global water supply. Not only are we over-dependent on imports for fuel and food - approximately 90% and 50% respectively. McCárthaigh S. (2008); Sheehan A. (2012) but also water. When we consider the embodied energy in treating and distributing water, and the ‘virtual’ or embodied water imported in food, goods and energy. 70% of the world’s fresh water supply is consumed in the production of food alone UNESCO (2013). Conservation is increasingly becoming an economic and business decision.

In a report compiled by the World Economic Forum, (2012) Martin Sorrell CEO of the wire and plastic products company, WPP says that we must take responsibility for our consumption as the worlds population increases, our climate changes, and water and natural resources become ever more scarcer.

1.1 *Sustainable Economics*

Growing our economy sustainably can be a way of future proofing the economy against the vagaries of scarce resources, higher prices, globalisation, transient multi-nationals and competitiveness in the market place. Being, acting and thinking sustainably are about understanding ‘the whole’. It is about looking at all the component parts simultaneously, understanding how they work together and the impact they have on each other. Thus this requires a new way of thinking or a new paradigm within which to think (WEF 2012). For example, any time we conserve any natural resource, we will tend to conserve all natural resources. Energy conservation and recycling both save water. Water conservation and recycling both save energy. For example, recycling a single aluminum can saves the energy equivalent of about half that can full of petrol. Thus it would be economically prudent to apply the ‘precautionary principle’. That is to say, that we should, 'play it safe' and begin to put in place measures to address these issues now rather than later. Simply put it will be cheaper to engage with these issues and seek to solve them now rather than in the future. But this requires a 'new way of thinking or a new paradigm within which to think,’ Gordon Brown (2011).

It is becoming ever more apparent that all business’ will need to adapt to a low carbon future and the recognition of the need to use materials and resources efficiently and that a workforce with appropriate skills is required is increasing. A publication on Skills and Employability by the International Labour Office (2011) states that the transition to a low carbon economy is one of the greater challenges facing governments, business, workers and organisations that represent them.

Until such time as economic ‘growth’ as is understood presently, is decoupled from societal development in the policy-makers psyche Ireland will not get clear thinking on this issue. Therefore any measures taken to up skill Irelands workforce with a non-holistic approach will not achieve the goal of a sustainable economy, (ILO 2008; EGFSN 2010).

This paper will look at why the Construction industry as a key player in the economy has to *‘think differently’* to fulfill its role in the drive towards sustainability, why attitudinal change is crucial and the importance of the educational process in bringing about that change. It will also explore the shift the construction education system itself has to make to be a real instrument of change in order to up skill our crafts people and embed sustainable economic growth.

2 THE NEED WITHIN EDUCATION FOR A SUSTAINABLE APPROACH

With global awareness of the need to develop sustainably it has become universally acknowledged that, like health and dietary issues, etc, that the path to embedding sustainable development is best achieved through education.

Sterling (1996) and Hopkins and Mc Keown agree that education is the key to change. Sterling says it has to be at the centre of the task both as ‘subject and agent’ i.e. not only is the content important but also the methodology. While Hopkins and Mc Known (1999) are unambiguous about the fact that ‘our current path’ will not bring about transition to a sustainable society and therefore we must take another approach using education.

Sterling (1999) citing his long experience of thirty years involvement in environmental and sustainable education says he has come to the conclusion about the need for a complete overhaul of the education system or as he says a paradigm shift is needed to change how we view the world in order to embed an environmental ethos.

Hopkins and Mc Keown (1999) say in effect it is about teaching people not only skills and knowledge but also perspective, and values, which will allow them to live sustainably.

And further research bears this out, with some researchers believing that knowledge alone is not adequate to produce a change in behaviour. In other words, knowledge does not provide citizens with the skills to combat environmental problems (Clifton, Mauney, Falkner 1998).

The UK produced document *Nudge, Think, Shove* (2010) states that the traditional ‘information provision’ approach is unable to take into account the entire social, political and institutional factors that form attitudes and behaviours.

When one considers that the present education system may be having quite a detrimental effect on the environment a paradigm shift is of the utmost importance. Presently, we are being educated to ‘compete and consume,’ rather than, ‘care and conserve’ (Mc Nerney and Deakin 1996). As it stands, most educational theory and practice still supports *unsustainable* practices. A UNESCO report (2002), notes that a ‘new vision’ and a deeper way of thinking about education is needed because the current education system falls short of what is required to bring about a sustainable future.

This paradigm shift in education would create a citizenry who would apply sustainability principles to their everyday lives, thus enabling society to become more sustainable (Hopkins, Mc Keown 1999).

Furthermore, as sustainable education by its nature embeds itself in the local community where its based its teaching methodologies and curriculum will be tailored to the needs of that community thus increasing awareness, community integration and social adhesion while equipping the student to live in a sustainable way within their environment and community.

But no community is isolated and self sustaining and thus people need to have a broader understanding of the wider economy, the more complex globalised economy and society and the impact their personal actions can have on the environment both locally and globally.

3 THE CONSTRUCTION INDUSTRY TODAY

While seen as ‘dirty, dangerous and old fashioned’ (Myers 2004) the construction industry has been identified as having a crucial role in the move towards sustainability - mainly because it encompasses more than any other sector the three corner posts of sustainability: economics and environment and society. But while being a positive force for economic growth its impact on environment and community are more often than not negative.

As we move towards a low carbon society, the construction industry has to lead the drive towards sustainability (World Economic Forum 2012). And to be part of this drive the construction sector must incorporate issues of social justice and wider concerns such as food, fuel and water security and sovereignty; future proofing against poverty; while considering the general wellbeing and future needs of its occupants and the community within which its situated.

3.1 *Barriers to change in the Industry*

The Construction Industry as it stands is seen as fragmented; inefficient; dogged by short-term thinking; fractious cross-disciplinary relationships and slow to change with little or no regard for both its employees and communities. It is a sector, which operates through bringing together disparate components, professions and personalities to work for a short time, often under financial and time constraints, on a specific complex project. It is the single biggest drain on resources and is seen as highly wasteful. Myers (2004) states that it has a devastating effect on the environment and is responsible for the use of large amounts of resources and the generation of large amounts of waste.

The ILO (2006) state that lack of environmental awareness among stakeholders in the building process is a significant factor in constraining green building.

Moreover, in what has being termed ‘the circle of blame’ none of the key drivers in the construction industry accept responsibility for lack of sustainable practice in the industry and due to the fragmentation of the industry no one wants to make the first move. Myers (2004) says this is a product of ‘*mindset*.’ Builders argue that they can only build what they are asked for, developers say there is no demand and investors won’t take the risk. Resolving inherent inefficiencies in the build process is seen as crucial in ensuring sustainable development.

3.2 *Sustainable Building*

Sustainable building on the other hand: through a holistic approach; integrated design and build processes; long-termism; checks on negative environmental impact and wastage; concern for occupants and community, priortises efficiency. This efficiency which underpins sustainable philosophy and as found in Sustainable building parallels that which economists, capitalists and the industrial sector continually strive for and is often referred to by Sustainable thinkers as the ‘triple bottom line’ or ‘win-win-win’ (Myers 2004). Such is the result when solutions that solve more than one problem simultaneously are found.

Sustainable Building is broader in scope than traditional building practice and includes integrated design build processes, and a social justice component. In other words it considers the impact the building and the building process will have on the society and community within which it is being built. Thus the definition of building must be broadened to incorporate an awareness of the built environment and the impact it has on occupants and the wider community.

4 CHANGING MINDSETS

Due to the complex nature of Sustainability, achieving sustainable development is not as easy as providing people with a particular set of practical skills because one cannot cover all the variables i.e. the combinations and permutations of potential problems that may arise. Thus each individual must be equipped with a new paradigm to enable them to think critically and assess and make decisions for themselves but decisions, which are grounded in sustainable principles. Lyle (1994) says that coming to understand ecological process in not just about learning another subject but fundamentally changing the way we view the world.

One obstacle to achieving the sustainable building approach is the compartmentalisation of disciplines within the building industry. What is needed is a process that brings together the work of various design and engineering management and craft disciplines. An idea which is gaining currency in commercial building is the Integrated Design Process. Which brings together the whole team to ensure quality and efficiency of the build. This process is the beginning of viewing the building as a whole unit or single system. It reduces friction between the disciplines and makes for a more efficient building process.

4.1 *World View, Attitude and Actions*

Our personal attitudes, which determine our actions are based on an all-encompassing worldview, or ‘model of thinking’ which is a product of our society, our families, our communities, our education system. Thus changing attitudes is a complex task and understanding and changing them in the context of sustainability is even more complex and an in depth analysis of attitude formation is beyond the scope of this paper. However, it is through underlying perceptions, assumptions, and cultural mores that we filter all our decision-making. And the present world-view is not necessarily pro-sustainability and in fact is often anti-sustainability.

Over the last three hundred years, a world view which regards the cosmos as a nurturing living organism and treated nature with respect has been gradually eroded and replaced by a world view which regards nature to be dead and can be exploited (Huckle 1996).

The present world view (Modernity) considers the environment as a commodity (Huckle1996) and there for mans disposal. This overarching view underpins much of the reasoning behind why the environment has been exploited, both as a generator of wealth and a waste disposal unit. John Tillman Lyle (1994) says that our present attitude towards the earth dates back to the renaissance and is not only out of date but also dangerous.

This is the worldview that presently underpins the education system and which our leaders, our managers and our future builders engage the world with. This is the worldview that most of our decision-making is based on. It impacts on our politicians, policy makers, analysts and strategists and educators and consequently on how well the system does or doesn’t work.

4.2 *Opposing World Views.*

Dunlap and Van Liere (1978) identified two fundamental paradigms; 1/ the Dominant Social Paradigm (DSP) which outlines the world view that guides our personal and policy decision making presently and 2/ the New Environmental Paradigm (NEP) which they envision is to replace the DSP in order to move society towards an environmentally friendly stance. Simply put, the present world view is anthropocentric and places man at the centre giving him the right to manage his natural surrounding as he wishes, while the NEP is an eco-centric woldview which values all life-forms equally (Grenstad et al 2006).

From an economic point of view the main difference between both worldviews can be summed up as;

Priority for economic growth and development. Focus on short-term or immediate prosperity.
Versus;
Priority for ecosystem viability, focus on long-term sustainability.

This dichotomy encapsulates the different approaches to the economy out of which comes two different sets of goals / policies and thus two different economic systems. One which will maximise growth at the cost of pollution and the other which aims to reduce waste and avoid pollution even at economic cost.

The NEP prioritises societal wellbeing over wealth generation at all costs. It emphasises foresight and planning to secure a bright future rather that reliance on markets to spur economic growth. It emphasises personal growth rather than material wealth. It focuses on horizontal structures that maximise interaction and learning as opposed to hierarchical and authoritarian models. It promotes, encourages greater personal and local responsibility. It recognises the need for holistic/integrative thinking as opposed to simplistic cause/effect thinking and narrow expertise. It emphasises co-operation, partnership and egalitarianism as opposed to competition domination and patriarchy. It places humans in an ecosystem context as opposed to subordinating nature to human interests.

The DSP is still guiding the way we think thus implementation of sustainable actions and achieving the goal of sustainability and a sustainable economy is impeded.

4.2 *Attitudinal Change*

Rogerson et al (1996) say; business people politicians and policy makers now accept that patterns of behaviour have to be modified in order to bring about change. There is a diverse range of views on how to stimulate this attitudinal change. Ranging from the use of legislation to enforce compliance; economic instruments such as tax breaks or grants and consciousness raising be it through the provision of information to the general public via ad campaigns or education (Department of Enterprise, Trade and Investment, 1996).

The U.K. report titled; *'Nudge, think or shove? Shifting values and attitudes towards sustainability'* (2010) says the goal is to find the optimal mix of these three strands, nudge think and shove, to bring about change in social values. But it is considered that the 'think' approach or deliberate action, which brings about attitudinal change, is more effective over the long term.

Our society approaches the issue of sustainability presently with a 'bolt-on' attitude. E.g. Bolting on a solar panel or introducing technological solutions without considering the whole i.e. from the whole build system process through to the lifestyle of the occupants. Likewise it is not good enough to add-on 'sustainable' modules onto traditional education courses. In essence a whole new educational paradigm centered around four pillars; holism, systemic thinking, sustainability, and complexity is what's needed (Mc Nerney and Deakin 1996*)*.

4.3 *Education for Sustainable Development*

Education for Sustainable Development (ESD) differs from traditional teaching methodologies in that it uses a whole-school multi-disciplinary approach with curriculum developed in conjunction with and by the students and based on the needs of the region/community within which the learning centre is based (Hopkins and Mc Keown, 1999). Huckle (1999) is in agreement with this suggesting that communities and educational systems need to work together towards a sustainable outcome, the community setting sustainability goals and the education system modifying its curriculum to underpin support and reinforce these goals.

Due to its complexity and holistic nature an interdisciplinary approach must be taken to its teaching. Such an educational approach will require the help of many disciplines focusing on interconnections between the natural and built environment, and the economic and political forces that influence the world around us (Mc Nerney and Deakin 1996). Thus traditional methods of education based on compartmentalisation of subjects needs to be dismantled. A multidisciplinary approach, which utilises a variety of educational tools such as case-based collaborative learning, problem-based learning, community focused education, service learning and an extant body of knowledge from across the disciplines to draw on must be engaged. Such an approach in itself leads to an educational process, which develops other core skills such as systematic thinking, communication, teamwork and interdisciplinary understanding. Sterling states that people should be engaged in a ‘critical pedagogy’ or participative action research (Huckle 1999) these skills are crucial in solving complex environmental and social problems in the real world - a big part of which entails building relationships and understanding the needs of all involved. This fulfils what Steven Sterling calls putting the relationship back into learning.

To meet the demands of a low carbon sustainable economy and society I propose that change needs to occur in the educational process in order to bring about change in the building industry.

I have shown that fundamental attitudes based on an outmoded world view need to change to embed this new way forward and that education is key, not only as a tool to facilitate the dissemination of knowledge and skills but also to changing these attitudes. I propose that the present education process itself has to change in both method and content by introducing a ‘holistic systems thinking’ approach, in order to bring about this fundamental change; equip our builders with the necessary problem solving skills and promote a greater understanding of the relationship between building, habitation and society.

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Tomorrow's sustainability: Devising a Framework for Sustainability Education of Future Engineers and Architects.

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ABSTRACT: Given the pressing issues related to sustainable development of current human activity, and being aware that cities, buildings and engineering projects in general are an essential part of impacts on environment, society and economy, it seems vital to act immediately in these sectors. Besides measures to integrate research and direct application in the professional sector, to act on the future professionals from the university is a key objective. With this scope, a review of what sustainability curriculum means is showed and it is proposed a first approach for its integration into a Polytechnic School, Universidad Europea (Spain).

1 SUSTAINABLE DEVELOPMENT AND APPROACHES

The need for a sustainable development in all human activity has been established as a fact. Thus, sustainability integrates the complexity of social, economic and ecological, so people can live with equal rights and duties, the economy allow fair distribution of wealth, to cover basic needs and optimizing the use of resources, respecting all forms of life preserving biodiversity. Sustainable development consists in finding the balance between the development of human societies and the natural cycle dynamics.

Currently it is accepted that these three dimensions should have the same relevance, order and importance. Sustainability is therefore balanced interaction of these three concepts (triple bottom line). This concept was first described in the business world in order to implement the concept of sustainability (Elkington, 1994). The current concept of sustainability is tending to differentiate these three dimensions but the continuous economic variable currently has a greater importance on the rest (Segalas, 2009). The other approach established the environment as the context and the limiting factor in all decisions. Subsequently society and culture are actors on the environment and decisions must be prioritized to meet the needs of the population. Finally would be the economic dimension as a medium of exchange to support social and environmental relations and not vice versa.

2 EDUCATION FOR SUSTAINABILITY

2.1 *Importance of sustainability in higher education*

Sustainability has reached the field of education, especially universities which have been linked to sustainable development since its inception. Even though the concept was not fully defined in the Stockholm Declaration of the United Nations Conference on the Human Environment in 1972 it is proposed the necessary interconnection between education and sustainable development.

There is a consensus in the literature: higher education institutions are crucial in the global efforts for reaching a sustainable development (UNESCO, 2009; Mochizuki and Fadeeva 2008 Calder and Clugston, 2003).

It is proposed in the literature promoting a solidarity education, overcoming the tendency to guide behavior based on short-term interests, or simple habit that contributes to a correct perception of the state of the world, building responsible behavior in students and preparing them to make decisions aimed at achieving a culturally pluralistic development and sustainable physically (Delors, 1996). At the World Summit on Sustainable Development held in Johannesburg in 2002, in the Ubuntu Declaration on Education and Science and Technology for Sustainable Development, it is also recognized education as a fundamental pillar for the implementation of sustainable development. In December 2002 the General Assembly of the United Nations declared the decade of Education for Sustainable Development from January 2005. And then it was stressed that education must play a key role in order to ensure sustainable livelihoods opportunities, and future for young people (UNESCO 2009). Currently there is being some consensus internationally on the role of the university in relation to sustainability, named and claimed worldwide (Calder and Clugston, 2003; Wright, 2004; Brundiers and Wiek, 2010; Mochizuki and Fadeeva, 2010).

Thus education in all areas has been marked as the basis of sustainable development. For UNESCO the challenge is how to achieve through education and learning throughout life that changes occur in lifestyles and behaviors of individuals that enable a more just and sustainable for all (UNESCO, Bonn Declaration, 2009). However, for some authors, which will lead to sustainability is a complete change in the global paradigm of education and involvement of society as they feel that education is often part of the problem encourages individualism, the unsustainable lifestyles and consumption patterns, directly or by default (Wade, 2008).

In some countries like Spain, the CRUE (Conference of Rectors of Spanish Universities) has prepared and issued the appropriate educational guidelines for the implementation of sustainable development competencies. These guidelines are described in the document "Guidelines for the Introduction of Sustainability in the Curriculum CRUE 2005", and include the following capacities to be able to develop the different professionals:

- Be able to achieve understanding, understand and consider in their professional interaction they have with society and the environment
- Understand the contribution of their work in different cultural, social and political
- Be able to work in multidisciplinary teams and transdisciplinary
- Participate in the discussion, definition, design, implementation and evaluation of policies and actions to redirect society towards a more sustainable development.
- Apply professional knowledge according to universal ethical values
- Collect the demands and proposals of citizens.

Engineering and architecture within their professional activity is a key actor, of the economic, social and environmental transformations. "*This society needs scientists, engineers, and business people who design technological and economic activities that sustain rather than degrade the natural environment; activities that enhance human health and well-being*" (Ségalas, 2009: 1).

Engineers and architects are actors of the present and future builders. To do this they need to be immersed in the problems and challenges that arise in today's society, so they can collaborate with other professionals to solve it. To do this it must create a technology education with the potential to help students to think, process, design and build in a more sustainable way (Elshof, 2005).

2.2 *How to develop sustainability into the university: skills and competences*

In the Bonn Declaration in 2009 it was determined that sustainable development should be applied with different approaches depending on the context, and through education it should integrate sustainability through teacher training, with better plans and study programs, materials, etc., incorporating sustainability among its key elements.

Sustainability into the curriculum is set as a strategy that tends to facilitate the achievement of training objectives relating to the development of basic skills for sustainability in university graduates (Aznar and Ull, 2009). Also, sustainability implies a wide range of expertise, knowledge and skills for action, integrating ethics education in the future (Geli de Ciurana, 2004), and those skills must be an integrated and complex set of knowledge, procedures, attitudes and values that individuals bring into play in different contexts when interacting to resolve situations (Geli de Ciurana, 2004).

For United Nations Economic Commission for Europe (UNECE, 2011), education for sustainability is based on an ethic of solidarity, equality and mutual respect between people, countries, cultures and generations, and its horizon has three fundamental characteristics: a holistic vision, a vision of change that learns from the past and the transformation of the meaning of being an educator and ways of learning and teaching.

Sustainable Education is about learning skills, perspectives and values that guide and motivate people to seek more sustainable ways of living, to participate in a democratic society and to live in a sustainable way. This involves studying local and global problems. Therefore, there are five components (knowledge, skills, perspectives, values and problems) to be included in a formal academic program that has been reoriented to address sustainability (Mckeown, 2002). The concept of "*Gestaltungskompetenz*" -conformation of competition- (Haan, 2006) as a result of the German experience, identifies the following core competencies: forecasting, intercisciplinar job skills, cross-cultural thinking, participatory skills, planning and implementation, empathy and motivation. This concept is characterized in particular by the key competencies required for the future participation and autonomously in setting sustainable development. (Adomßent and Hoffmann, 2013)

Core competencies emphasize the mobilization of knowledge: knowledge is not enough to acquire, retain and memorize to repeat, we must know how to use knowledge of different types (linguistic, technological, relational, concepts, strategies, attitudes) in a consistent manner and appropriate circumstances in changing contexts (Arizaleta, 2010). It is not to add one more element in the academic level, but to integrate it into the educational process in a holistic manner (Conference of Rectors of Spanish Universities, "Guidelines for Curriculum Sustainabilization" April 18, 2005, Valladolid).

Flexible curriculum models should be developed to facilitate the holistic perspective of human development environmentally and socially sustainable and it is needed to work in teams and networks to foster greater diversity of research contexts, action and interaction. It is for this reason that education for sustainability emphasizes creative and critical approaches; it encourages critical reflection that allows becoming aware of actions and questioning them; and the innovation and empowerment for dealing with uncertainty and solve complex problems enter in the learning process (Ull et al, 2010). This challenge commit professors to manage processes based on action research, defined as a collaborative process in which managers and researchers would combine research, learning, reflection and action (Ull et al, 2010).

Also noteworthy is that the implementation and assessment of competences for sustainable development vary, because each country has a unique combination of issues to be addressed through technology and education for sustainable development (Pavlova, 2012), although all within a common framework that has been determining internationally through various declarations, conferences and publications.

In the learning outcomes and competencies of graduates in engineering, obtained from a recent study (Segalas, 2009) shows a consensus (on the sample) of the competencies that are most important in the three domains of learning:

- Knowledge and understanding: State of the World, The causes of unsustainability; Fundamentals Sustainability, Science, technology and society sustainable technology tools.
- Skills and abilities: Auto-learning and work-disciplinary cooperation, sustainable development Solve; critical thinking; Social Participation.
- Attitudes: Responsibility, commitment and knowledge; Culture of Respect and ethical values; awareness.

2.3 *Integration of Sustainability in Higher Education*

The International Commission on Education in its report to UNESCO, "LEARNING: The Treasure Within", recommends that all reforms are carried out in the spirit and essence of sustainable development and calls for reorienting education in this field.

Focusing on the implantation of sustainability in the university field, the Steering Committee of ECE established a Group of Experts on Competencies in Education for Sustainable Development in 2009. Its mandate, among others, was the development of a series of basic competences in matter of Sustainability in Education to serve as tool in integrating these concepts in all educational programs of all levels (UNECE, 2011). This is a transversal way to integrate sustainability, by developing skills all along the graduation.

A complementary way to achieve these goals is the introduction into the curriculum a course whose content is Education for Sustainability or Education for Sustainable Development, a trend that is spreading in European universities (Firth and Winter, 2007). In this case we must take special care that the other subjects do not stop to contemplate the skills for sustainability.

Despite this, overall transverse integration of various courses is considered much more effective than the mere addition of specific courses dedicated to sustainable development. Students can evaluate as less important or whose contents can be perceived as far from their future profession, therefore not integrated with the rest of its competences. For the implementation of sustainable development is necessary to emphasize the application of a broad and general approach (Sammalisto and Lindhqvist, 2008). Some universities started with the objective focused on a less complex concept such as the environment, to now moving towards the paradigm of sustainability, as the University of Catalonia (Ferrer-Balas et al, 2004).

The priority is to motivate educators to understand, accept and introduce sustainable development concepts and strategies into their teaching programs. The concepts introduced so far are loose threads, while the Education for Sustainable Development is a concept more holistic, comprehensive and interdisciplinary (Down, 2006). Also we do not forget that university has to meet the expectations of students: a curriculum must maintain its focus on course objectives so that the demands of sustainability issues not displace the selected course (Down, 2006).

3 PLAN FOR SUSTAINABILITY EDUCATION 2012-2016 – UNIVERSIDAD EUROPEA

From the information that is being developed and was summarized before, the European University has proposed its Sustainability Plan 2012-2016 recently that seeks to integrate sustainable development transversely through the development of key skills. Initially it has been selected five but they will be increasing each year by the feedback obtained, according with the research project supported by this university (Esteban et al, 2013). Thus, initial skills are: critical thinking, initiative and entrepreneurship, responsibility, capacity for analysis and synthesis, decision making, and, finally, aware of ethical values.

But education for sustainability is not only the development of skills in a curriculum, we believe that a good sustainability plan must also develop internal sustainability (to employees, students, etc., at the institutional level), where raw the example in the daily chores of the university; and external sustainability in the University's relationship with other stakeholders (suppliers, companies, employers, research labors, etc.) leading by example and taking a leadership role in this social field. This should be further beyond corporate social responsibility and environmental and quality management that currently many institutions develop and take a step towards education for sustainability.

It is crucial professor training in innovative topics such as sustainability. It has been organized the First Meeting of Curriculum Sustainabilization nationwide in Spain (January 2013), specific workshops with internal and external experts in the field, and some workshops on innovative teaching conferences. Currently at the European University a total of 329 courses developed curricular sustainability issues in 2012-2013 of all degrees given. Note that in this first pilot year, we just try to have the first feedback from students, professors and rest of stakeholders to develop a good strategy to reach in a medium term an integrate education for a sustainable development. In this sense, the project have many problems to face: changing competitive learning (such as normal works of students) by cooperation learning; identification of numerous activities and forms of teaching assignments that are flawed precisely in those aspects we want to avoid, without encouraging the spirit critic; in definitive: it is being identified a major effort to this new challenge.

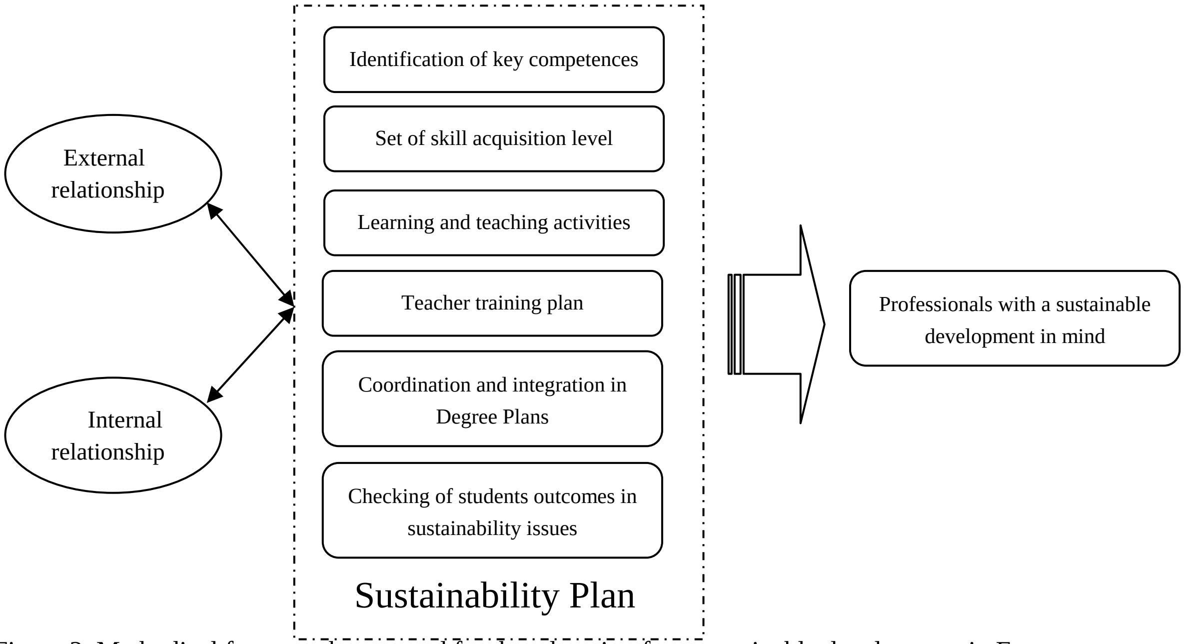

Figure 2. Methodical framework proposed for the education for a sustainable development in European University

The steps proposed as a methodological framework in our Sustainability are (as shown in Figure 2): the identification of all key competencies to be made (by the comparison with other universities, declarations, and consensus); to develop acquisition levels in each competence and teaching activities to develop each one; the qualified profile of the future graduate linked with the skills we want to develop; and to develop tools to test the acquisition of different sustainability skills of graduates and their level of acceptance by employers with the added value that this training may result.

4 CONCLUSIONS

The paradigm shift involved in education for sustainable development makes professionals and teachers to change our course of action. Professionals influence now. Teachers influence on tomorrow's professionals. In a self-critical first revision teachers can become aware of the amount of information and activities that we do in the classroom that tend to repeat anti-sustainable models for our students. It is necessary, therefore, a reflection of how we want tomorrow's professionals and act accordingly in the classroom. Not an easy task, but the challenge is well worth it.

It has been explained in this paper a review of the approaches on the concept of sustainable development and, mainly its relation to education at university level. It is shown that educational level is focusing on competencies and professional sector materializes sustainability through indicators. These skills are developed differently in different contexts, but it seems that there starts to be consensus in relation to a number of key skills considered in the literature and IFAs. Based on the literature and on the needs of the Spanish case and the context of the European University it has proposed a Curriculum Sustainability Plan, with a methodological framework to be developed during next three years, until 2016, beginning to grow. The main objective in a medium term is to obtain graduates with a high professional profile plus great people.

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Chapter 3

High Performance Sustainable Building Solutions

Cost/benefit analysis in the implementation of sustainable construction principles in a residential building

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ABSTRACT: The construction sector is one of the major contributors for the increase of pollution and environmental degradation. The uncontrolled increase on the consumption of natural resources, the way they are used and the high emissions they arise, are impelling the study and implementation of policies and procedures which ensure a sustainable future for construction and for the sustainability of the planet. The objective of this paper is to present the work developed in order to assess and optimize the sustainability of a residential building at the design stage, through the application of a sustainability assessment tool, SBTool^{PT}-H. A first evaluation was done, when conventional solutions were adopted. After this, a proposal was developed with several improvements in order to create a sustainable building that corresponds to the Portuguese best practices. This case study was developed taking into account the twenty-five sustainability indicators of the SBTool^{PT}-H assessment system. Additionally, dynamic thermal simulation was used in order to support the optimization of the thermal performance and the indoor thermal comfort.

1 INTRODUCTION

The construction sector is one of the major contributors for the increase of pollution and environmental degradation. The uncontrolled increase on the consumption of natural resources, the way they are used and the high emissions they arise, are impelling the study and implementation of policies and procedures which ensure a sustainable future for construction and sustainability of the planet.

The development of building sustainability assessment and certification systems in different parts of the world is enabling the reduction of the negative impacts of the construction sector, the optimization of life-cycle costs and the development of a built environment with higher comfort patterns for occupants.

The objective of this paper is to present the work developed in order to assess and optimize the sustainability of a detached house at the design stage, through the application of a sustainability assessment tool, SBTool^{PT}-H (Martinho, 2013). A first evaluation was done, when conventional solutions were adopted. After this, a proposal was developed with several improvements in order to create a sustainable building. The presented sustainable proposal was developed taking into account the twenty-five indicators that constitute the SBTool^{PT}-H assessment system (Mateus & Bragança, 2011).

Since the energy efficiency and the thermal comfort are two parameters that most influence the overall sustainability of a building, the methodology used in this research also included dynamic thermal simulation in the optimization of the sustainability of the case study.

An economic analysis is also performed to analyse the cost/benefit related to the proposed sustainability improvement measures. Thus, this work highlights the contribution of the building sustainability assessment tools in the development of more sustainable buildings, as a process to ensure the level of efficiency of buildings in relation to the consumption of natural resources, environmental protection and thermal comfort.

2 THE SBTooL^{PT}-H METHODOLOGY

The SBTool^{PT}-H is based in the adaption of the international Sustainable Building Tool (SBTool) to the Portuguese's environmental, societal and economy contexts. The scope of this methodology is to assess the sustainability of the existing or new and renovated buildings in the urban areas an especially in Portuguese context (Mateus & Bragança, 2010).

A variety of sustainability assessment tools is available on the construction market, and they are widely used to assess the environmental performance of building products. Therefore the majority of tools to be used on building level were developed in a bottom-up approach, i.e. the overall performance comes from summing up the contribution of building materials and components to the whole building performance. There are several LCA based tools available that were especially developed to address the building as whole. This issue is discussed, for example, in Forsberg A. & Malmborg von F. (2004).

In the Sustainable Building Tool (SBTool) the approach is to weight different criteria, considering weighting factors that are fixed at the national level. Each "score" results from the comparison between the studied building and national references (conventional and best practices). This scheme allows an international comparison of buildings from different countries.

This methodology is intend to be a tool to support the building design in order that this achieves the most appropriate balance between the different sustainability dimensions, and that is at the same time practical, transparent and flexible enough to be easily adapted to different kind of building and technology (Mateus & Bragança, 2011). The framework of this methodology is presented in Figure 1 and is described in Mateus & Bragança (2011).

The methodology follows four steps: i) Quantification of performance of the building at the level of each indicator; ii) Normalization of parameters; iii) Aggregation of parameters; iv) Sustainable score calculation and global assessment.

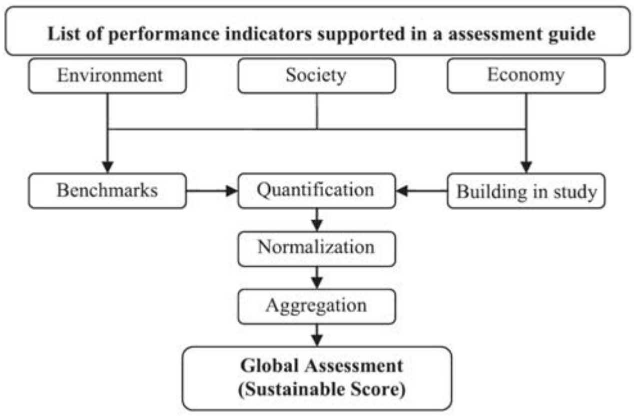

Figure 1. Framework of the SBTool^{PT}-H methodology (Mateus & Bragança, 2011).

3 PRESENTATION OF THE CASE STUDY

The case study is one residential building, for one family, with two floors (Level 0 and Level 1) and a floor for the garage (Level -1), giving a total construction area of 515.28 m^2 and a gross footprint of 245.25 m^2. The residential building is located in Casal Velho, near to the city of Pombal, in the Leiria district. The building is defined by a traditional structure, namely in reinforced concrete and the exterior and the interior walls are made of hollow brick masonry.

The land plot has 421 m2 and is near to the urban area of Casal Velho. The buildings surrounding this case study are medium/low density, predominantly defined by residential detached buildings (for one family). The distance between the center of Castelo Velho and the city of Pombal is around 3 km. In Figure 2 to 5 are presented the plans of the building under study.

As abovementioned, the building is designed according the traditional construction techniques used in Portugal: reinforced concrete for the structure (beams and columns) and 25 cm thick hollow-brick single walls in the external vertical envelope. The building uses an External Thermal Insulation Composite System (ETICS) as the basis if the thermal insulation. Interior walls are in 11cm thick hollow brick. The walls, interior and exterior, are coated with traditional Portland cement mortar.

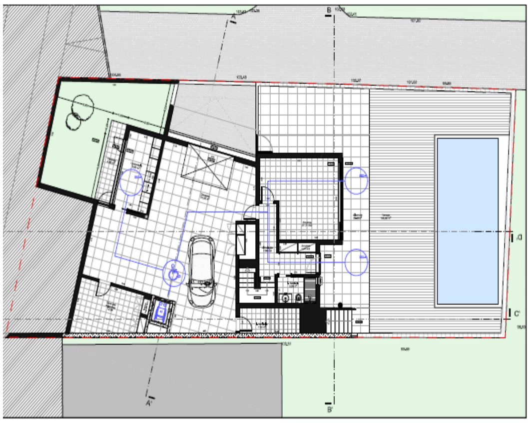

Figure 2. Plan of the Level -1

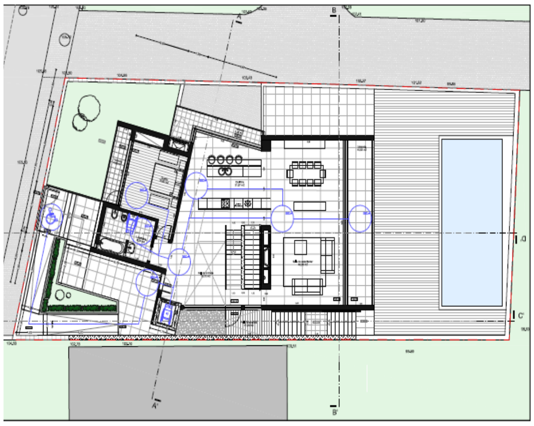

Figure 3. Plan of the Level 0

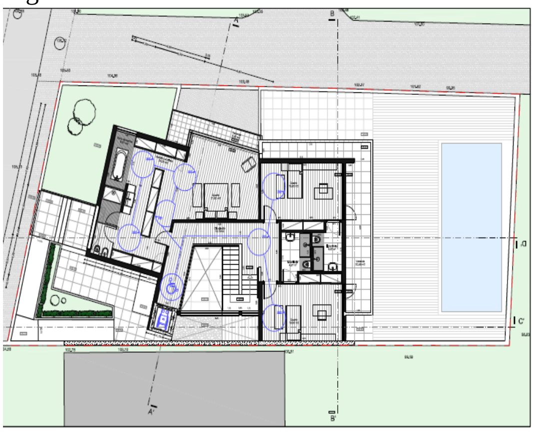

Figure 4. Plan of the Level 1

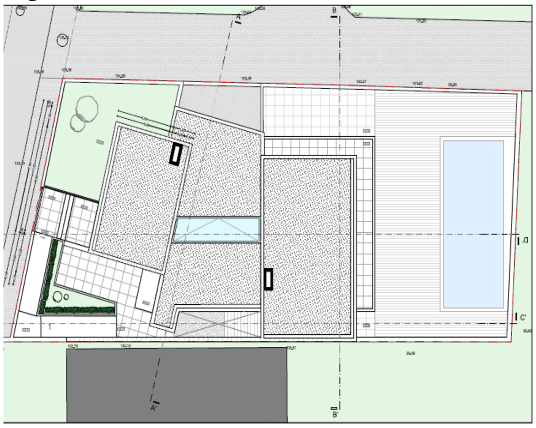

Figure 5. Plan of the Level of the roof

4 ASSESSEMENT OF THE SUSTAINABILITY

The implementation of the sustainability assessment was carried our according to the evaluation guide and the assessment procedure of the SBTool^{PT}-H methodology and follows the steps indicated in the Figure 1. To assess the environmental dimension the authors used an embedded life-cycle impact assessment (Bragança & Mateus, 2012). This database covers the most used building technologies for each building element (walls, floors, windows, doors, etc.). The physical boundary of the SBTool^{PT}-H methodology is the building site plus the level of integration of the building with other urban amenities (e.g. commercial areas and leisure areas). The time boundary it includes the whole life cycle, from cradle to grave.

The performance of the case study, assessed for the original solution and for the optimized solution, is measured against each category, sustainable dimension and global score (sustainable score)

4.1 *Original Solution*

The first step is the quantification of the performance of the original building at the level of each sustainability indicator. Table 1 lists the categories and sustainability indicators and respective results from the application of the SBTool^{PT}-H methodology to the original solution.

Table 1. Sustainability assessment of the original building

Dimension	Categories	Sustainability indicators	Original solutions	Score level
Environmental	C1 - Climate change and outdoor environment quality	P1 - Construction materials embodied environmental impact	Exterior walls: Single 25 cm ceramic thermal hollow brick wall. The thermal insulation is complemented with an ETICS(6cm polystyrene and polyethylene net); Interior walls: 11cm thick hollow brick masonry wall; Structure: reinforced concrete columns and beams and reinforced concrete slabs; Finishing: i) walls – Portland cement mortar (indoor and outdoor); ii) floors – ceramic tiles and insulation in level -1 and humid areas and wooden floating floor in the other areas; iii) ceilings – suspended plasterboard ceilings with rock wool in the air gap.	A (0.75)
	C2 – Land use and biodiversity	P2 – Urban density	Total gross construction area of 515.28 m^2; a footprint of 245.25 m^2. The land plot has 421 m^2.	A^+ (1.18)
		P3 – Water permeability of the development	Traditional flat roof. The exterior land, surrounding the building, is permeable.	D (0.05)
		P4 – Use of pre-developed land;	Virgin land without any contamination and previous construction.	D (0.00)
		P5 – Use of local plants	There are 41.0 m^2 for green spaces and no local flora is used.	E (-0.20)
		P6 – Heat-island effect	There is a lake(water mirror) to reduce the heat island effect, but most of the surface is paved.	E (-0.20)
	C3 – Energy efficiency	P7 – Primary energy	The architecture takes advantage from passive solar strategies with shading elements and a favourable solar orientation.	A (0.95)
		P8 – In situ energy production from renewable sources	It is planned the application of solar panels for water heating.	A^+ (1.20)
	C4 – Materials and waste management	P9 – Reused materials and products	It isn't planned the use of reused materials in the construction.	D (0.00)
		P10 – Use of materials with recycled content	The used materials have a conventional recycled content.	D (0.00)
		P11 – Use of certified organic materials	No certified materials are used.	D (0.00)
		P12 – Use of cement substitutes in concrete	Concrete with 6.2% of fly ashes.	A^+ (1.16)
		P13 – Waste management during operation	Point of collection and separation of waste (recycling center public) between 50 and 500 meters; Lack of domestic ecopoints.	D (0.0)
	C5 – Water efficiency	P14 – Fresh water consumption	Conventional taps and equipment's are used.	C (0.167)
		P15 – Reuse of grey and rainwater	There is no rainwater harvesting system.	D (0.00)
Societal	C6 – Occupant's health and comfort	P16 – Natural ventilation efficiency	Openings with large are allowing efficient natural cross ventilation.	A^+ (1.20)
		P17 – Toxicity of finishing	Applied materials with low COV content.	A^+ (1.11)
		P18 – Thermal comfort	Not considered in the assessment, since there was no data from dynamic thermal simulation in the original project.	
		P19 – Lighting comfort	Proper solar orientation. There are no obstructions in the openings.	A^+ (1.20)
		P20 – Acoustic comfort	Double glazed windows Large openings. External walls in thermal hollow brick and external finished with an ETICS.	A (0.82)
	C7 – Accessibilities	P21 – Accessibility to public transportation	The plot is served by 9 lines of Bus.	A (0.70)
		P22 – Accessibility to urban amenities	The main urban amenities are within a maximum radius of 2500 m.	A^+ (1.13)
	C8 – Education and awareness of sustainability	P23 – Education of occupants	There is not a user manual.	E (-0.20)
Ec	C9 – Life-cycle-costs	P24 – Capital Cost	The cost per m^2 of initial investment is 851.38 €.	E (-0.20)
		P25 – Operation Cost	Lifecycle cost with Euribor tax 10.31 € per m^2 and year.	C (0.26)
Global score				B (0.53)

Each building element used in this case study is described. The performance of each sustainable indicator was obtained after the normalization and aggregation and is presented in Table 1.

The results obtained for the categories are: C1 - Climate change and outdoor environment quality: A (0.75); C2 – Land use and biodiversity: C (0.35); C3 – Energy efficiency: A+ (1.08); C4 – Materials and waste management: C (0.21); C5 – water efficiency: C (0.11); C6 – Occupant's health and comfort: A+ (1.08); C7 – Accessibilities: A (0.90); C8 – Education and awareness: E (-0.20); C9 – Life-cycle-costs: D (0.03).

The score obtained for each dimension is: Environment: B (0.63); Society: A (0.90); Economy: D (0.03). These results lead to a final score of B (0.53). Analysing this results it is possible to conclude that this building is level B due to its high initial investment and due to the low performance at the level of the sustainability indicators in the environmental dimension.

4.2 *Optimization of sustainability*

To optimize the sustainability of the building the methodology SBTool^{PT}-H was used and the most important indicators were considered. Therefore the implemented design alternatives were bases in the purpose of improving the most unfavourable indicators. At the end it was possible to archive an overall level of sustainability of A. The implemented actions are described in Table 2.

Table 2. Sustainability assessment of the optimized building

Categories	Sustainability indicators	Optimized solutions	Score level Optimized building
C1 - Climate change and outdoor environment quality	P1 - Construction materials embodied environmental impact	Use of green space near the pool instead of deck floor; application of a green roof; Replacement of aluminum shutters by shutters PVC; Replacement of geotextile provided by the TERBOND brand; Replacement of T61 and C31 of Amorim, lightweight concrete; Replacement of thermal isolation Roofmate SL-40, by Greycicle Key Boards; Elimination of the ceramic coating, existing in the exterior at the garage access, considering a green space.	A^+ (1.07)
C2 – Land use and biodiversity	P3 – Water permeability of the development	Use of green space near the pool instead of deck floor. Application of s green. Elimination of the ceramic coating and use of permeable flooring in the access to the garage.	B (0.56)
	P5 – Use of local plants	Use of green space near the pool instead of deck floor; Application of a green roof using native plants; Elimination of the ceramic coating and use of permeable flooring in the access to the garage, using native plants.	A^+ (1.06)
	P6 – Heat-island effect	Use of green space near the pool instead of deck floor; Application of a green roof using native plants; Elimination of the ceramic coating and use of permeable flooring in the access to the garage, using native plants.. Application of materials with a color reflectance greater than 60%.	A^+ (1.13)
C3 – Energy efficiency	P7 – Primary energy	Implementation of high performance glazed areas; Implementation of a pellets boiler; Application of photovoltaic panels.	A^+ (1.77)
C4 – Materials and waste management	P13 – Waste management during operation	Application of containers of various categories of waste with volumes greater than 15 L. Implementation of used oil and used batteries containers.	A (1.00)
C5 – water efficiency	P14 – Fresh water consumption	Implementation of tap with aerator; dual flush toilets of low capacity 4/2 litres; low flow showers; washing machines with low water consumption.	A^+ (1.07)
C8 – Education and awareness os sustainability	P23 – Education of occupants	Development of a user manual that covers the main building sustainability aspects related to the operation phase.	A^+ (1.20)
C9 – Life-cycle-costs	P25 – Operation Cost	Lower operation costs, resulting from the use of high performance equipments and building elements.	A (0.74)
Global score			A (0.75)

The results obtained for the categories are: C1 - Climate change and outdoor: A+ (1.07); C2 –

Land use and biodiversity: A+ (1.03); C3 – Energy efficiency: A+ (1.19); C4 – Materials and waste management: C (0.25); C5 – water efficiency: A (0.71); C6 – Occupant's health and com fort: A+ (1.08); C7 – Accessibilities: A (0.90); C8 – Education and awareness: A+ (1.20); C9 – Life-cycle-costs: C (0.27). The score obtain for each dimension is: Environment: A (0.90); Society: A+ (1.04); Economy: C (0.27). Due to this optimized assessment, the environmental performance of the building was improved to the level A and the societal performance achieved the maximum level. In what respects to the economic performance, it was also improved, but due to the high initial investment a level C was obtained. These results lead to a final score of A (0.75), Table 2.

4.3 *Analysis of the thermal behavior of the building*

The building was analysed using the simulation tool Design Builder. The assessment was done before and after the optimization. These studies intended to analyse: the energy losses by the several materials that constitute the building envelope; the energy gains in the building; the behaviour of the internal temperatures of the building due to the variation of the external temperatures along the day and year; the energy consumption of the building, for heating and cooling the indoor environment and to maintain the thermal comfort during both the heating and cooling seasons.

Table 3 shows that the consideration of optimized solutions in the building induced a better thermal performance and a reduction of operation costs. For the dynamic analysis of the thermal behaviour of the building the comfort temperatures of 18 ºC for winter and 21 ºC for the summer were considered, taking in consideration the comfort class level III of the standard EN15251:2007. To assess the energy costs the following reference costs were considered: i) pellets - 0.24 €/Kg; electricity - 0.139 €/kWh. These were the valued in the local market in November 2012.

Table 3. Evaluation of the thermal behaviour of building and related operation costs

Compartment	Original building				Optimized building			
	Energy demands kWh/year		Energy costs (€)		Energy demands kWh/year		Energy costs (€)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Living room ($90.42m^2$)	350	2200	28.23	305.80	600	1600	29.39	222.40
bedroom ($2160m^2$)	150	450	12.10	62.55	300	350	14.69	48.65
WC ($4.87m^2$)	35	110	2.82	15.29	35	110	1.71	15.29
All building ($245.25m^2$)	1950	5450	157.30	757.55	1800	4350	88.16	604.65

4.4 *Economic analysis*

In order to get a better understanding of the developed work and the achieved classification for the building, after the analysis of sustainability and the thermal behaviour an economic analysis was developed. Table 4 represents the life cycle costs of the building for the two analysed solutions: the original and the optimized.

Analysing Table 4 it is possible to conclude that the implementation of the sustainable solutions results in a reduction of costs by 1.5 times between and the improvement of the sustainability from B to A. At the end of a life cycle of 50 years the implementation of the optimized solution has a saving of 67,827.60 €. It should be noted that these analyses do not comprehend the gains from the sale of electricity to the public system, due to the production of electricity from photovoltaic panels. According to the photovoltaic panel design, the annual energy production is about 3042 kWh/year. The energy price in the subsidized regime is 0.306 €/kWh, for the first eight years and 0.165 €/kWh for the remaining seven years. After fifteen years the values for sale and acquisition are equal. According to the main Portuguese energy supplier, in 2012 the normal energy price is 0.139 €/kWh.

From the abovementioned values it can be conclude that he use of photovoltaic panels results in a gain of 13,074.50 €, considering a period of 20 years for the life cycle of the photovoltaic panels.

The graph shown in Figure 6 reflects the evolution of total investment during the entire life cycle of the building with original solution, class B, and optimized solution, class A.

Table 4. Life cycle costs of the building attending the two solutions.

Costs	Original building (Class B)		Optimized building (Class A)	
	Initial unit value (€)	Total life cycle (€)	Initial unit value (€)	Total life cycle (€)
Maintenance				
Replacement of the floor coating each 20 years.	12,185.80	24,371.60	12,185.80	24,371.60
Painting exterior, interior walls and floors each 8 years.	3,756.00	22,536.00	3,756.00	22,536.00
Replacement of the glazed openings each 30 years.	6,811.00	6,811.00	8,757.00	8,757.00
Operation costs (245.25 m^2)	€/m^2.year		€/m^2.year	
Energy consumption.	2.82	34,580.30	0.93	11,404.10
water consumption, wastewater production and solid waste.	9.87	121,030.87	4.76	58,369.50
Totality of the operation costs using the Euribor tax (1.23%).	10.31	126,426.38	4.62	56,652.75
Totality of life cycle costs with Euribor tax (1.23%)	-	180,145.10	-	112,317.60

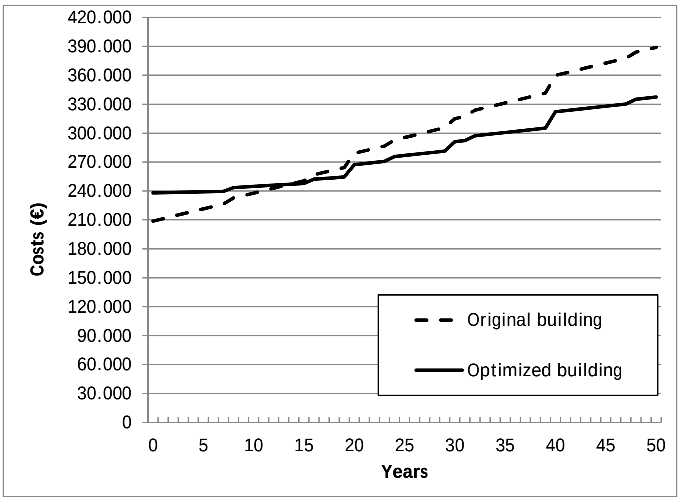

Figure 6. Evolution of the life cycle costs of the original and optimized alternatives.

It can be seen that the initial investment of 29,285.20 € in sustainability solutions are recovery at the 13th year of the life cycle of the building. At the end of the life cycle the building with Class A, has a total investment of 337,330.08 €, whereas the building with Class B has 388,946.60 €, representing a total of savings of 51,616.82€.

It can be concluded that investment in sustainability measures is profitable, with a quick payback time and representing significant savings at the end of life cycle.

5 CONCLUSIONS

The work presented in this paper is aimed to assess and optimize the sustainability of a residential building at the design stage, through the application of a building sustainability assessment tool, namely the SBTool^{PT}-H. A first evaluation was done, where conventional solutions were adopted. After this, a new proposal was developed with several improvements in order to create a sustainable building with a higher level of performance, corresponding to the Portuguese best practice (level A). An economic analysis is also performed to analyse the cost/benefit related to the proposed sustainability improvement measures.

As this paper highlights, the improvement of the sustainability of a building does not relies only in the preservation of the environment, but also in the consideration of social and economic aspects. The sustainability of a building depends not only on one dimension but in the harmony between the three dimensions of sustainability: environmental, societal and economic.

This research and the application of the methodology SBTool^{PT}-H allowed the development of the following conclusions to conclude that:

Sustainable building needs less extraction of raw materials and produces significantly lower greenhouse gases to the environment;

The consumption of water and energy are substantially smaller in sustainable building;

The economic analyses demonstrate a clear cost reduction from the sustainability level B to A, which would result in significant savings in life cycle of the building.

The building with sustainable level A has a much better thermal behaviour that the building with sustainable performance class B. This classification is also reflected on the energy consumption necessary to maintain the building in the range of thermal comfort.

In what respects to the contribution of the methogology SBToolPT-H to the sustainable building design, it is possible to highlight that:

This methodology is a clear aid to the design of sustainable residential buildings. This framework based in the analysis twenty-five sustainability indicators covers the key points of sustainability.

It allows making improvements in the design of the residential buildings in order to ensure a better performance at the level of the three sustainability dimensions: environmental, social and economic;

It addresses the thermal comfort, giving special attention to the energy consumption and associated costs to keep the building in the range comfort.

The assessment of the sustainability of a building is an advanced vision, which shows that small options can be crucial for the environment, society and economy.

This work highlights the importance of the evaluation and certification of the sustainability of the construction, as a process to ensure a level of efficiency of buildings in relation to the consumption of natural resources, environmental protection and thermal comfort.

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Water Reuse for Domestic Consumption
A Key Element For Environmental and Economic Sustainability

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ABSTRACT: In a context of increasing social awareness about resources conservation, residential water management is essential in ensuring environmental and economic sustainability. An adequate management is attained with integrated solutions, which simultaneously reduce potable water consumption at least in 25% and enable the storage of recovered water.
The recovery and storage of underground water can be ensured with the installation of a groundwater drainage network and an underground water deposit, which will supply the residential toilet cisterns and the automatic irrigation systems through independent piping. These solutions aim to achieve high levels of water conservation with the aid of known materials, components and techniques, with as little interference as possible in residential comfort. They also reduce the interference in the water cycle, since less public water is used for residential consumption and the surrounding surface permeability is assured in order to allow the infiltration of rainwater into the soil.
Due to water reuse, the cold potable water consumption in residential buildings can be reduced in up to 50% when compared to average consumption in buildings without recovery systems. Therefore, the environmental and economic impact analysis of water reuse leads to the conclusion that the investment has a five year payback period, after which it represents a real gain for residents.

1 INTRODUCTION

Fresh water is a scarce and valuable resource in the XXI century, due to population growth, climate changes and environmental pollution. About 25% of world population lives in areas with shortage of drinking water, which has led to an uneven distribution of water, lack of food and humanitarian catastrophes (Molden, 2007). The availability of water depends on the amount of rainfall, the collecting area and the quality and length of treatment and distribution infrastructures (Halliday, 2009).

Predicting that there will be a drought stress equal or superior to 40% in 2025, according to World Water Council (WWW, 1996), it is necessary to take important measures, one of which being presented in this studyis to increase water efficiency in buildings.

Researchhas been made in cooperative buildings which have the capability of reusing water. Furthermore, we have determined and compared results, which have been obtained in the context of sustainable construction under controlled costs, aimed at residents of the Portuguese cooperative housing. Knowing that sustainable construction is nowadays an international recurrent concern, we focused on saving resources and environmental impact reduction on the current use of the heritage building cooperative, as well as the future construction of new cooperative projects.

2 WATER MANAGEMENT IN RESIDENTIAL BUILDINGS

The main goal of sustainable water management is to ensure the effectiveness of its use and minimization of pollution, so that water returns to the environment in a benign way (Roaf et al., 2007). In what concerns residential buildings, demand for water has been increasing due to exponential construction of dwellings and to the use of water consuming appliances such as washing machines by almost every families. The establishment of gardens and recreational green areas involves the construction of irrigation networks and also a marked increase in drinking water consumption.

Regarding water quality, all the water that enters each building has got the quality of drinking water, but all of it comes out as sewage. An increase in its use affects the infrastructure, the storage requirements and the necessary energy to distribution and purification. Generally, water is inefficiently used, for example, by mixing and dissolving waste throughout the entire cycle.

The reduction in water consumption, although it can be made economically (by reducing the price of water) and sociologically (by environmental education), it is essentially ensured by technical means, through the efficiency of the products (toilets, showers, washing machines). Thus, the sustainable use of water in buildings must pass through "water efficiency of products" (Rodrigues & Silva-Afonso, 2007).

By reducing water consumption in buildings, water cost and waste water treatment cost will be smaller, and the following benefits will be achieved (Nicholls, 2008; Todd, Benjamin & Todd, 2007):

- Reduced consumption of hot and cold water, which corresponds to energy saving;
- Reduction of energy used to treat and pump water supplies and waste water;
- Reducing the amount of chemicals used in water treatment;
- Reduced maintenance costs as a result of water recovery;
- Reducing the impact on the water supply infrastructure;
- Improving environmental protection and therefore preserving water resources.

The water stress risk has increased very quickly on the planet. In countries, such as Portugal, it may occur, in 2025, a very serious situation of water shortage. In terms of water saving chances in Portugal, it is currently estimated that the total of water use inefficiencies is higher than 3×10^6 m³ / year (National Program for the Efficient Use of Water). The economic value of these inefficiencies will exceed 750×10^6 € / year, representing about 0,64% of Portugal's Gross Domestic Product. About half of this amount can be considered as savings opportunities in the urban infrastructures and in water systems in residential buildings.

Groundwater and rainwater have traditionally been collected for reuse in gardens. However, according to Nicholls (2008) and Halliday (2009), for internal uses this water should be diverted wherever possible, filtered and stored in an underground storage water tank.

As groundwater and rainwater arenot allowed to be used as drinking water, their use is restricted to toilet flushing and garden watering. The pipe systems shall be clearly marked to avoid the risk of cross contamination. All tests and water facilities shall be made, under regulations, to ensure that the system is safe and presents no health risks.

In Portugal, the use of rainwater presents two important constraints:

1 -Water distribution managing authorities do not authorize the use of non-potable water within a dwelling, according to article 86 of the Law-Decree n º 23/95 of 23rd of August. However, for cooperative ventures promoted in the municipalities of Porto and Vila Nova de Gaia, after submission of a technical study of recovered water for flushing toilets and irrigation, they were exceptionally accepted in favor of cooperation between public authorities and sustainable cooperative construction. Even so, the supply was only authorized if a direct monotubular pipe was used to supply toilets, embedded throughout its course without tees or taps.

2 - In residential buildings, a storage cistern for recovered ground and rainwater would be installed in the basement and sub-basement, below the level of the street pavement that gives access to the basement. In accordance with paragraph 2 of Article 205 ° and 206 ° of the Law

Decree 23/95 of August the 23rd, the waters gathered below the street pavement, even if located above the collector public, should be raised to a level equal to or higher than the street. This arrangement would involve the installation of an hydropneumatic group for pumping rainwater in excess on storage, which is not sustainable in case of normal rainfall or, worse, in possible situations of peak rainfall, leading to flooding of the particular basement.

Due to the previously described circumstances, it appears that the use of rainwater is only possible in very particular cases (Ponte da Pedra, 2007), in which the storage tank could be placed above the level of surrounding streets.

In other situations, in which it is not possible to place a storage tank above street level, it can be considered that water recoveryis only feasible after confirmation, via surveys or geological and geotechnical studies, of the existence of groundwater located at the level or above the basement, whose waters can be drained directly to the storage tank. The durability and permanence of groundwater must be confirmed by measuring heights for a consecutive year, in order to determine dimensions and flow rates compatible with the supply to the building intended (Guifões, 2007; Madalena, 2008). If so, given that this water would need to be collected, in all cases, in a well on the ground floor and pumped to the outside, it will be advantageous to proceed to the design and construction of storage tanks for later re-use the water.

3 METHODOLOGY

The case study was based on the comparative analysis of the consumption of drinking water of four cooperative housing developments.

As a sample of a multiple case study we considered four housing projects, chosen from the set of cooperative ventures promoted by Housing Cooperatives under controlled costs. The samples were divided into two groups: the projects completed after 2006, representing sustainable construction, and developments completed before 2006, representing a traditional construction, non-sustainable:

- Madalena (Vila Nova de Gaia) - 2 buildings, 39dwellings (2009)
- Fontainhas (Porto) -1 building, 27 dwellings (2009)
- Leça da Palmeira (Matosinhos) - 1 building, 29 dwellings, (2007)
- Azenha de Cima (Matosinhos) - 1 building, 36 dwellings (1993)

In this research, it was carried out monitoring, comparison and analysis between building performances, regarding the consumption of drinking water, comparing building systems and equipment used in the three projects referred to as sustainable construction (Madalena, Fontainhas and Leça da Palmeira) with the building identified as traditional construction (Azenha de Cima).

For the analysis and comparison between quantitative data, monthly consumptions of drinking water for the total amount of 131 dwellings were collected and analyzed.

A comparison matrix of relationship between building systems of the two groups of cooperative enterprises and their performance has been made. This matrix focused on the field of saving drinking water, as well as in the improvement of environmental comfort for residents (with a consequent increase in the quality of life of residents cooperative - the social aspect), and in the reduction of harmful emissions into the atmosphere and reducing the consumption of potable water per capita (with the consequent impact on improving the environmental impact of sustainable construction –the environmental aspect).

Regarding the economic aspect, this focused on the analysis of the annual amount in savings of drinking water. The calculation of the annual consumption of drinking water, according to the records of actual consumption of the four projects under study was aimed at defining the level of resource requirements considered adequate for the normal use of the buildings by the 131 families.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 *Analysis of building systems and equipment*

In Table 1 we presented the main systems and equipment included in building construction, which were observed on site. In this table are presented the four cooperative projects, three sustainable and one non-sustainable.

Table 1 –Systems and equipment for water management included in building construction

System	Madalena	Fontainhas	Leça da Palmeira	Azenha de Cima
Bathtubs with thermostatic valves for controlling water temperature	Yes	Yes	Yes	No
Toilets with dual flush mechanism	Yes	Yes	Yes	No
Taps with aerators	Yes	Yes	Yes	No
Underground tank of recovered water for garden watering, garage washing and toilets of dwellings.	Yes	No	No	No

It was given particular importance, during construction of sustainable buildings, to water management, according to the increasing sensitivity of the population to saving resources. The concern to ensure appropriate management of water, especially during its use by the residents, aimed at:

- Achieving high levels of water conservation, using techniques, materials and components already known, interfering as little as possible in the comfort of home;
- Limit interference with the natural cycle of water, reducing the amount of water pumped, and increasing the use of rainwater and transferring to the water cycle via local infiltration;
- Reduction of at least 25%of drinking water consumption compared to the current consumption patterns.

The above targets were achieved by the implementation of an overall solution, in terms of building equipment and housing, in order to, on one hand, reduce the consumption of drinking water and, on the second hand, store recovered water.

The recovery and storage of groundwater have been achieved through the construction of a drainage network of groundwater and an underground concrete tank, which supplies, by an independent pipeline, recovered water to the all the toilets of both Madalena buildings.

The water stored in the concrete tank comes from infiltration into the soil from rainfall, groundwater and water that is formed at the level of the floors of garages, which, by ground ascension, is captured by drains. This procedure is defined as "reuse" water is generally low cost of use and construction, but requires the use of water soil quality consistent with the purpose for which they are intended (Roaf et al. 2007). The soil water analysis, performed during the study the geological and geotechnical ground indicated that the water is free from harmful materials presented to any contact with humans. This water is used for the supply of toilets and for watering private gardens of the buildings.

The pipeline of recovered water within the dwellings is entirely separated from public supply of drinking water, intended only to toilet flushing.

We present, on Figure 1, a schematic drawing of distribution of recovered water to the toilets of one entrance of each Madalena buildings.

Regarding water savings, there were showers installed and equipped with thermostatic valves for temperature control, in bathtubs and shower trays as well as toilets with dual flush system. Thermostatic valves diminish the waste of water between the opening of the tap water and heating to the desired temperature. The possibility to adjust temperature and maintain fixed for future use, causes the water to exit at the desired temperature by the user without the need to manually adjust the temperature.

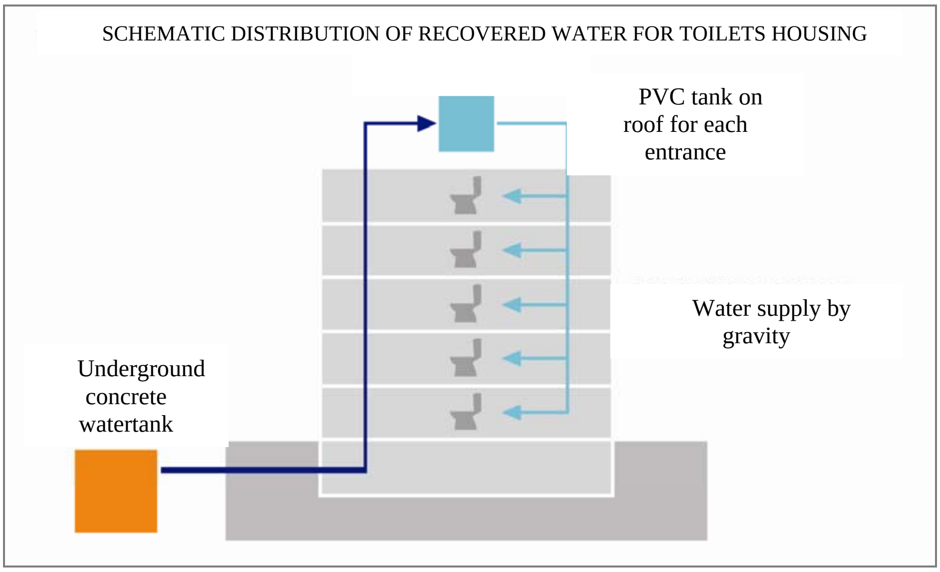

Figure 1 - Schematic distribution of recovered water for toilets housing

4.2 *Analysis of cold water records and consumption*

Records of water consumption were carried out for a whole year period for the existing sample of the four projects: Madalena (39 dwellings), Fontainhas (27 dwellings), Leça da Palmeira (29 dwellings) and Azenha de Cima (36 dwellings).
From the monthly records of cold water meters,figures were drawn of monthly consumption by dwelling. As an example of the monthly water consumption of housing for each project, is presented in Figure 2, their monthly consumption.

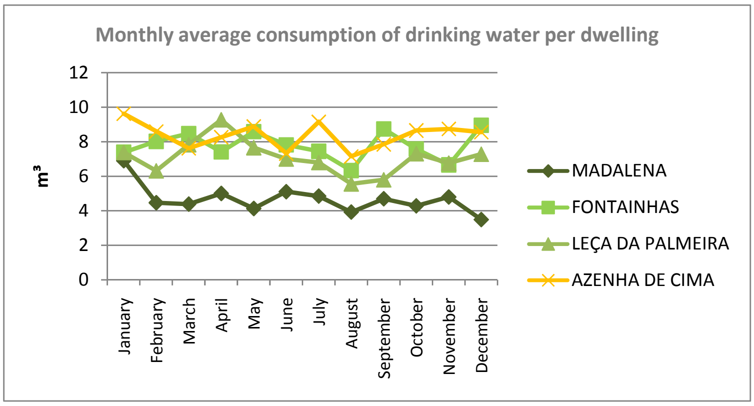

Figure 2 - Variation of the monthly average consumption of drinking water for each dwelling

By analyzing consumption, it is possible to draw some conclusions about the monthly average consumption of cold water by dwelling. The monthly distribution of consumption is done on a regular basis, around a mean value, which is as follows:

- Madalena: 4.67 m³ per month;
- Fontainhas: 7.78 m³ per month;
- Leça da Palmeira: 7.08 m³ per month;
- Azenha de Cima: 8.37 m³ per month.

There is a substantial difference in water consumption between Madalena and the other buildings. As explained before, the water used in toilet comes from the recovered water tank and is not therefore recorded in the water meters; in the 2nd case, all water consumed in the dwelling is registered on the counter.

This means that the residents of Madalena pay less for drinking water than residents of other ventures, because the water that supplies the toilets is free of cost. It is important to quantify this benefit, in what concerns the volume of drinking water saved and its cost saving, the analysis of the reduction of water stress, as well as the reduction of the cost of using the dwelling.

To support this fact, the records show that during the year 2011 in Madalena, passed by the totalising counters, an alternative to supplying drinking water to toilets when there is a shortage of recovered water, in July and August, months in which there wasn't any supply of recovered water, 117 m³ of water intended for flushing. Being 39 dwellings inhabited in Madalena, this means that each dwelling spent, per month, an average of 1.5 m³ of water for the toilets only. And we must conclude that, knowing that July and August are months in which residents spend their holidays, most of them leaving home for a fortnight or even a month, this figure is smaller than it shoud be if they were permanently at home.

With regard to average annual consumption, as shown in Figure 3, it is found that in Madalena, this is 56.00 m³ / year and per dwelling, and that for the other three projects, is 93.34m³ / year and per dwelling in Fontainhas,84.93 m³ / year and per dwelling in Leça da Palmeira, and 100.39m³ / year and per dwelling in Azenha de Cima.

The main conclusion of this analysis is that it is possible to assess the impact that the use of recovered water in toilets of Madalena has in the consumption of drinking water ofdwellings. At first sight it is observed that, in Madalena, each dwelling consumes 28.93 m³ less than in Leça da Palmeira (less 34%) and 37.34m³ (40%)less than in Fontainhas. In a second analysis, considering the ratios of inhabitants per dwelling (Madalena = 3.03; Fontainhas = 2.63; Leça da Palmeira = 2.76), drinking water consumption, per capita, it appears that, in Madalena, each inhabitant consumes an average of18.5 m³ of drinking water per year. This corresponds to 48% less than in Fontainhas (35.5 cubic meters per person per year) and 40% less than in Leca da Palmeira (30.8 cubic meters per person per year).

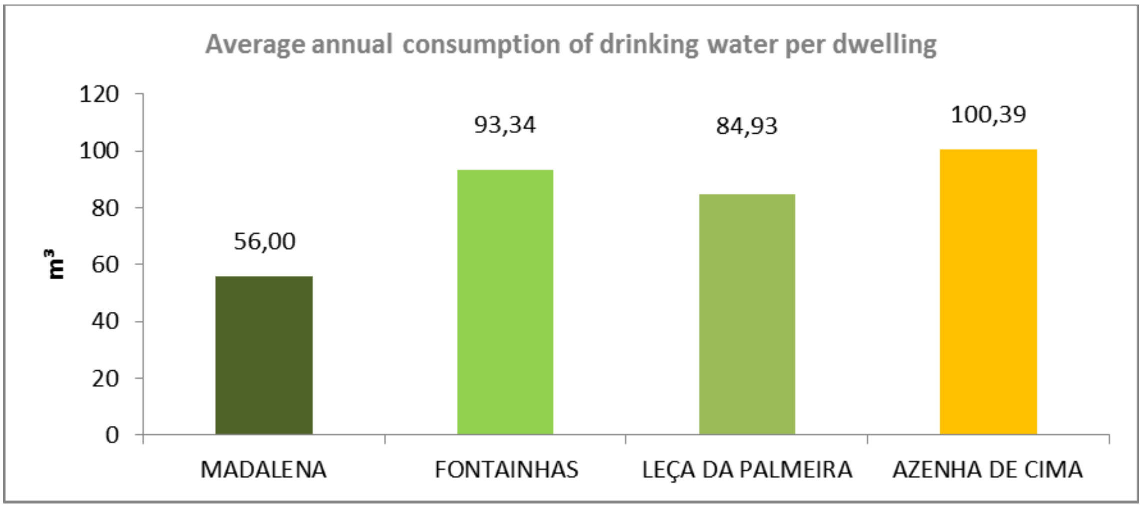

Figure 3 - Average annual consumption of drinking water per dwelling

Thus, the difference that appears between the average annual per capita consumption, in both types of ventures (with and without recovered water), corresponds to annual savings in the consumption of drinking water, due to the existence of recovered water, which corresponds to an average value of 36 m³ of water per year, equal to the difference between the annual consumption of Madalena and the annual average of the other three buildings.

4.3. *Analysis of savings by using recovered water*

It is expected to calculate the estimated annual savings of using recovered water in the dwellings. For calculating savings, consumption is established between drinking water consumption in standard projectsand Madalena. By comparing this average consumption with the average consumption of the remaining three projects that do not have such a system, it is possible to calculate the mentioned annual savings.

For this purpose, we use the values from monitoring of consumption: to determine the number of inhabitants of the building, we use the occupancy of 2 persons for the T1, T2 for 3 persons, 4 persons for T3 and T4 for 5 people, multiplying by the number of types described in Table 1, the total volume of water consumed per year in each project, it uses the value of the average annual consumption per capita, given in section 4.2. In this case, the building of Madalena, who has recovered water, consumes 18.51 m³ of water per year per inhabitant. The remaining three projects, which have not recovered water, consume, by determining the average, 92.00 m³ of water per year per inhabitant, as shown in Table 2.

Table 2 - Annual savings in usingrecovered water for consumption

	Madalena (sustainable)		Average (non-recov.water)		Savings per dwelling and year		
Type	Consumption m³/inhabitant	inhabitants	Consumption m³/inhabitant	inhabitants	m³ /.year	€ / m³	€ per year
T1	56.00	2	92.00	2	72.00	1.14	82.08 €
T2	56.00	3	92.00	3	108.00	1.14	123.12 €
T3	56.00	4	92.00	4	144.00	1.14	164.16 €
T4	56.00	5	92.00	5	180.00	1.14	205.20 €

By consulting the table mentioned above, it appears that, for a cooperative housing T1 with recovered water and two occupants, the annual expected savings in drinking water is 82.08€, corresponding to the difference in consumption per occupant presented above. Similarly, it is possible to carry out similar calculation for the other types, as shown in the same table.

4.4 *Payback period of sustainable water management*

This study shows that it is possible to measure cost benefits in sustainable cooperative construction. It is expected that a sustainable cooperative dwelling spends on drinking water, per year and per inhabitant, 41.04 € less than a dwelling of traditional cooperative construction. This difference is due mainly to a system of water recovering and the existing of a large capacity storage tank.

Consulting technical and financial data of Madalena project, it is possible to present the cost of this system, which is described in Table 3. As none of these materials and equipment was used in the other projects, it is possible to assume that the values shown in Table 3 represent the increase of cost associated to the implementation of sustainable water management.

The costs of these materials and equipment, for the 100 dwellings of Madalena buildings, were calculated in 68.725,54 €. This means that the cost of sustainable water management due only to water recovery, per inhabitant, is of 226.82 €. This value results from the calculation of the total inhabitants of Madalena buildings, which are 303.Assuming that Madalena building of spends less 41.04 € per inhabitant and per year than the other three buildings, and energy and maintenance costs are 2.11 € per inhabitant and per year,the payback period is of 226.82 €/ (41.04 € - 2.11 €)= 5.8 years, as shown in Table 3.

Table 3 – Cost of efficient materials and equipment of Madalena project and payback period for sustainable construction with standard comfort energy consumptions

	Cost (€)
Concrete watertanks	12,332.54
Water pumps	6,117.34
Pipe network for toilets and garden watering	47,002.84
VAT	3,272.82
Complete system of recovered water	68,725.54
Increase of cost per inhabitant due to recovered water	226.82
Savings in drinking water per inhabitant and per year due to recovered water	41.04
Cost of energy and water pump maintenance per inhabitant and per year	2.11
Payback period for water management with recovered water	5.8 years

5. CONCLUSIONS AND RECOMMENDATIONS

The study proves that sustainable housing cooperative built to provide high quality environmental, reduces the use of drinking water through the use of efficient building systems and equipment. For this purpose, design must gather sustainability criteria, enabling efficient management of water, with the application of devices that allow the reduction of consumption and the collection and storage of underground and rain water.

By monitoring performed to cooperative residential buildings, it was possible to conclude that the low monthly consumption of drinking water indicates that cooperatives have already developed an efficient use of their homes. However, it is possible to improve the efficiency of the use of resources, through the adoption of specific rules of behavior for savings in the consumption of drinking water. These savings, which positively affect the family budget, also decrease the pressure on infrastructure funding, production and distribution facilities in Portugal, reducing their demand and their costs, which contributes to a better environmental balance.

Therefore, it is essential to improve, in the future, the awareness of residents to the effective use of water. The decrease in water stress passes mainly through dissemination of concepts and rules conducive to the effective use of water. Housing cooperatives, using their newsletters and manuals of use and maintenance of their property, have contributed to arise awareness of the residents. Nevertheless, this type of information should be repeated at regular intervals, as though to result in significant water savings, these decrease as the behavior of water consumption patterns back to previous sensitization.

Finally, it is noteworthy, given the current economic and social, that the adoption of these and other practices of sustainable use of water and other resources, the ordinary citizen, is an individual and collective commitment.

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Energy consumption and thermal comfort in a passive house built in Romania

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ABSTRACT: This paper mainly presents the measured energy consumption and the variation of the comfort parameters of a passive house built in the city of Timisoara, Romania. Energy efficiency of the house and the thermal comfort offered to the occupants is directly connected with the proper design of the building envelope and the good functioning of the heat pump and of all the other equipment. In order to determine the real energy consumption of the building and to keep under observation the climatic comfort parameters and the good functioning of the equipment, the house is under continuous monitoring for over a year now. Thus, the residential building has a complex monitoring system composed of a series of sensors and electric data recorders which measure various parameters and the electrical energy consumption of the house. The monitoring system was installed in the idea of validating that the design of the house in terms of envelope and equipment is close to the passive house standard through both energy consumption and comfort offered to the occupants, regardless of the weather conditions. Currently, we have the monitoring data after more than one year of monitoring. So, the paper focuses on presenting the precedents regarding the annual energy consumption of the house after one year of monitoring, problems encountered with monitoring and data processing and also information about thermal comfort in the house.

1 INTRODUCTION

1.1 *General overview on energy efficiency and thermal comfort*

It is well known that the construction sector is responsible for a high percentage of energy consumption and consequently has a great implication in the depletion of global resources and environmental pollution (Ding 2007). Throughout the entire life-cycle of a building, approximately 80% of the total energy consumption occurs in the usage phase of the building. Therefore, a way of reducing the environmental impacts of a building is improving the energy performance of the building (Kashreen 2009). The European Union published the Energy Performance of Buildings Directive EPBD as a legislation regarding the energy performance of the buildings for the European member states and aims to promote improvements in the energy efficiency of a building. Measures such as increasing the thickness of thermal insulation, use of elements having low heat transfer coefficients for the envelope and usage of renewable or non-conventional resources are the main factors taken into account by architects, engineers, authorities and the society as a whole.

Throughout Europe there are many different concepts of energy efficient buildings that are generally known as buildings with a lower energy demand than common buildings. One of these concepts is the passive house concept. In order to achieve the passive house standard, a house must have an annual heating/cooling requirement for at most 15kWh/m^2/year and a total energy footprint of less than 120kWh/m^2/year (Feist 2007).

A passive house combines high-level comfort with low energy consumption. Passive components like insulation, advantageous orientation, heat recovery, air tight envelope are the key elements. Thanks to the high level of thermal insulation, heat recovery system and solar gains, a passive house doesn't need to be heated actively to a large extent. The low amount of additional heat which needs to be supplied is frequently realized with heat pumps (Ochs 2011).

Careful implementation of details and good planning are crucial in obtaining a building with very low energy for heating. A proper design and execution can lead to a high energy efficient building which consistently provides pleasant indoor and surface temperatures. The passive house concept can be adapted to any climate zone; the general approach is the same. Depending on the climatic conditions, the quality and type of components, materials and equipment may vary.

The research into passive houses proves good thermal climate during the winter season due to the additional insulation and air tightness of the building envelope. In Thullner's thesis two different opinions are presented regarding thermal comfort in a passive house in summer season. One of the statements sustains that in summer times the risk of higher indoor air temperatures appears compared to a traditional house. Due to the well-insulated and airtight envelope it is difficult to reduce these excessive temperatures. The second opinion sustains that it is possible to ensure comfortable indoor climate during summer without active cooling by ventilating at night when the outdoor temperature is lower and avoiding penetration of warm air at daytime. Thus, the low indoor temperature is maintained due to the well-insulated and air tighten envelope. The main idea is that high quality indoor thermal comfort can be achieved also during summer if the incoming warm air or overheating due to sun-faced gazed areas are avoided (Thullner 2011).

In Romania, passive houses are a relatively new concept. Currently there are five passive houses built in the whole country. This article refers to a passive house located in the city of Timisoara, west side of Romania. From climatic perspective, Romania is situated in an area with a temperate climate with four seasons. The differences between the temperatures in the hot season and the temperatures in the cold season are very high. Therefore, particular attention should be paid to both heating during winter and cooling in summer time. The purpose is to avoid temperature drop in the elements of the envelope during cold season and also to prevent overheating in the hot season.

By monitoring the passive house from Timisoara, the energy consumption is measured and temperatures are kept under observation. After a relevant period of monitoring some conclusions can be drawn regarding energy efficiency of the building and the thermal comfort offered to the occupants.

1.2 *Characteristics of the passive house built in the city of Timisoara, Romania*

The monitored passive house built in Romania is part of a duplex and has a usable area of approximately 144 m^2. The house was designed and built so that the construction costs are minimized (Stoian et. al. 2012). Common materials were used, such as reinforced concrete, bricks, wood and polystyrene. The house has a regular shape and a compact volume so it was easy to achieve an air tight envelope and minimize thermal bridges. Opaque elements of the envelope were insulated with expanded polystyrene plates. So, for the walls a polystyrene layer of 300 mm thickness was used. The roofing system is a non-traffic terrace, with a slope of 2%.

Due to the very high level of thermal insulation, the heating demand of the house is low and the heat supply is realized with an air-water heat pump. The domestic hot water production will be assisted by solar energy through a solar panel. The presented house uses a ventilation system with heat recovery. Therefore, most of the heat is contained inside the house, preheating the intake air for the ventilation system through underground heat exchangers.

In Figure 1 are presented the layers of the roof for the passive house and in Figure 2 is presented the stratification for the foundation and ground floor of the house. As we can notice, these envelope elements are very well-insulated aiming to achieve the passive standard.

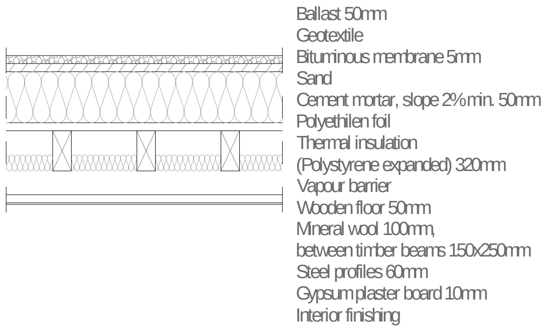

Figure 1. Layers used for the roof terrace.

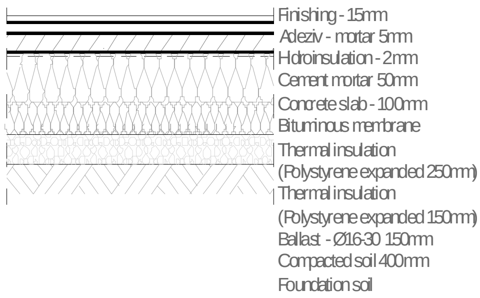

Figure 2. Layers used for the ground floor.

In the design phase of the building the energy demand was assessed using the Passive House Planning Package PHPP in order to see if the residential building is a passive house in the concept stage (Feist et. al. 2007). Evaluating the theoretical energy performance of the building by using the PHPP tool allowed the designer to test different design solutions against a set of criteria. Thus, was obtained a value of 15 kWh /m^{2}year for heating and cooling. The results are promising and indicate that the house is properly designed and can achieve the passive house standard.

2 MONITORING THE PASSIVE HOUSE

2.1 *Implementation of the monitoring system and measured energy consumption*

Implementing the monitoring system in the passive house built in Timisoara, represents a practical way of verifying if the design adopted for the studied house leads to the desired and expected results of energy efficiency. The system registers and collects data which is uploaded to a web server where diagrams available for online visualization are created.

The components of the monitoring system result from the need to make data available online and the physical measurements that had to be taken. Therefore the system contains a central unit and a number of ambient/energy flow meters. The monitoring system records data from 41 sensors, with the measuring pace set to 1 minute (Sabau et. al. 2013).

After more than one year of monitoring there is sufficient recorded data in order to assess the annual energy consumption of the building and thus evaluate its energy performance. The energy consumption of the building is monitored through 4 electric data recorders (Table 1). It is expected that the higher energy consumption to be registered for heating, ventilation and hot water. The energy consumption for household appliances can have large variations which generally depend on the behavior and lifestyle of the occupants and number of household appliances.

Table 1.Electrical energy consumption sensors.

Recorder ID	Electrical energy consumption	Unit
EL1	House hold	W
EL2	Lighting	W
EL3	Heating, ventilation, hot water	W
EL4	Exterior	W

In Figure 3 is presented the monthly electrical energy consumption of the building divided by categories of consumers. As we can see, for the winter months is recorded a much higher energy consumption than for the rest of the year. The consumption is much higher due to the heating demand of the house in the months with low temperatures. We can see that during the year the energy consumption for heating, cooling and ventilation vary greatly compared to the other consumptions.

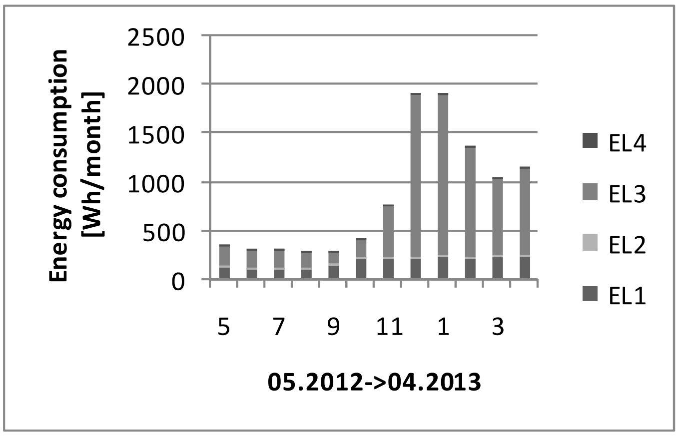

Figure 3. Monthly electric energy consumption.

The total specific energy consumption of the building obtained through monitoring is 45.8 kWh/m^{2}year and the specific energy consumption for heating, cooling and ventilation is 19.85 kWh/m^{2}year, which is more than calculated with PHPP. From the heating and cooling energy consumption perspective, the discussed house does not subscribe the passive house standard but the difference is slightly small.

2.2 *Analysis of the thermal comfort parameters*

An essential criterion of thermal comfort is the temperature difference between the surface temperature of the envelope element and the temperature inside the room (C107/2005). Some studies present recommended guideline values for thermal comfort and hygienic climate in a residential building. The recommended operative temperature for winter times varies between 20° C and 24° C and for the summer the guideline values are contained between 23° C and 26° C (Thullner 2010). Normally, in case of a passive house, the well-insulated envelope ensures that in the winter months the heat stays in the house, meaning: evenly warm surfaces in the room, uniform and constant indoor climate and no fluctuations in temperature.

In Figure 4 and Figure 5 we can observe how the interior temperatures vary in the cold season and in the hot season.

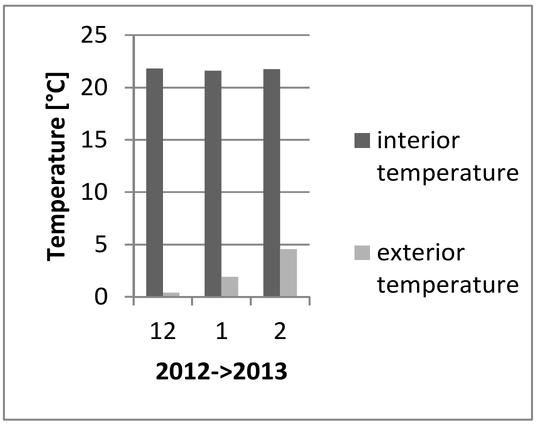

Figure 4. Temperatures in winter months

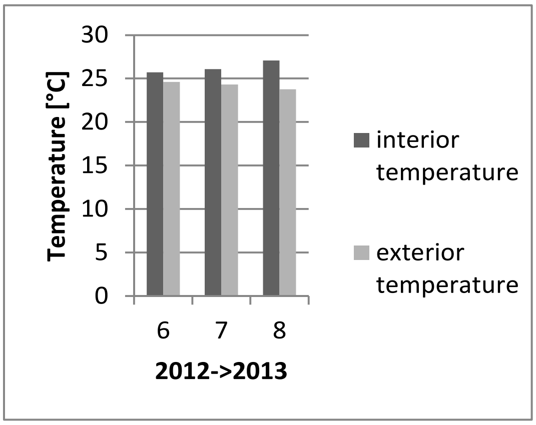

Figure 5. Temperatures in summer months.

From the charts represented in Figure 4 we can observe that in winter conditions the temperature inside the house is kept at adequate values for thermal comfort. On the other hand, for the summer season we can notice in Figure 5 that the registered temperatures are slightly higher than recommended. After processing the data recorded by the temperature sensors mounted across the wall we managed to obtain the variation of the temperature from exterior to interior. The results for the winter and summer months are presented in Figure 6 and Figure 7.

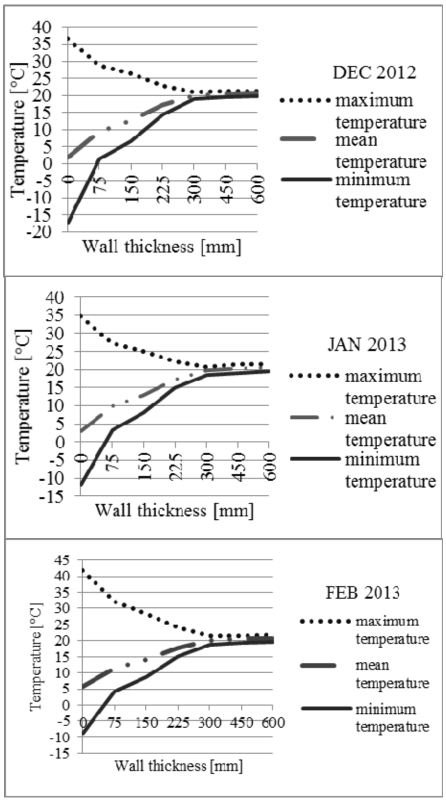

Figure 6. Wall temperatures in winter months.

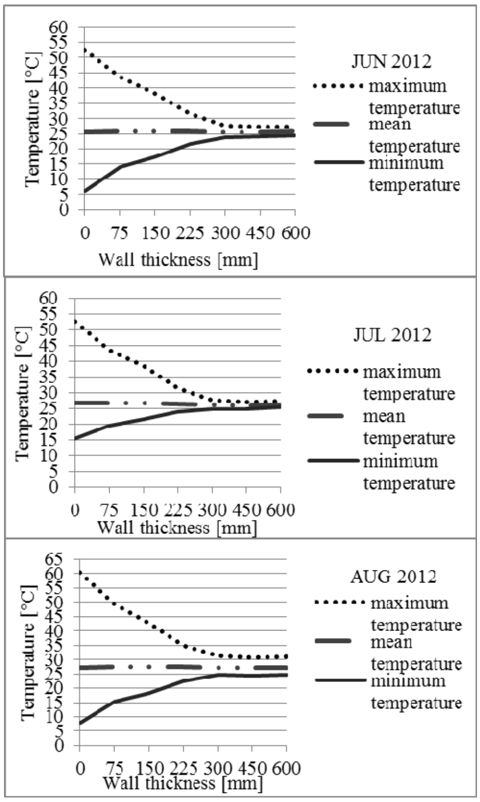

Figure 7. Wall temperatures in summer months.

By analyzing the graphics for the winter months (Fig. 6) we can see that despite the big difference between the temperatures at the exterior surface of the wall, the temperatures within the wall, starting from the interface between the polystyrene plate and masonry, strive to remain constant. Comparing these temperatures with the interior air temperatures (Fig. 6) we can state that the difference is very small, for about 1 or 2 Celsius degrees. In summer season (Fig. 7) we can notice a slight overheating of the envelope element where the temperatures at the inner surface of the wall tend to values between 25 and 30 Celsius degrees.

Figure 8 shows how the interior air temperature varies with the exterior temperature during the monitoring year.

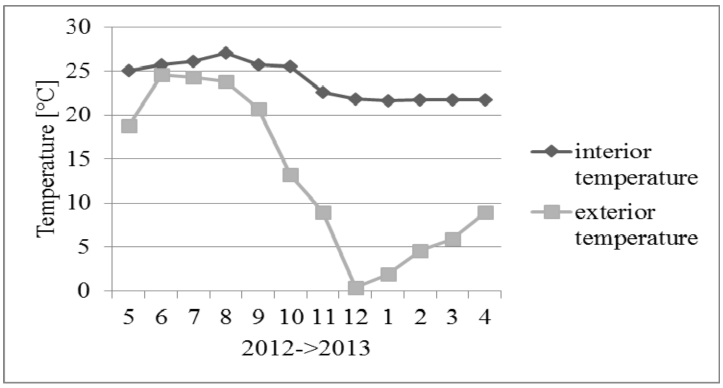

Figure 8. Interior and exterior temperature variation during the monitoring year.

As we can see in the chart in Figure 8, the interior air temperature, in both warm and cold months, has values which largely comply with the recommended guideline values for thermal comfort and hygienic indoor climate, independent of the exterior temperature. This fact proves effective thermal insulation and also effective building solution chosen for the envelope element.

3 CONCLUSIONS

The research presented in this paper suggests the growing attention and consideration for the need of building energy efficient houses, being passive houses or nearly zero-energy buildings. Although the passive house concept is not widespread in Romania, such a house can easily be built using techniques and materials which are common in the construction industry of the country.

Implementing a monitoring system in a low-energy house is essential for validating its energy performance and moreover it can lead to further improvement in energy efficiency. Monitoring of the passive house built in the city of Timisoara, Romania, led to a series of relevant conclusions that might be helpful for further development of such type of houses and improvement of the used techniques, planning and detail.

The energy consumption results obtained after one year of monitoring are approximately equal to the estimated consumption in the design phase. As presented earlier in this paper, the registered energy consumption for heating/cooling is 19 kWh /m^2year, value which is slightly higher than the estimated value of 15 kWh /m^2year. On the other hand, the total registered energy consumption is 45.8 kWh /m^2year. This value is far below the value of 66 kWh /m^2year, calculated in the design phase. The value of the total energy consumption of the house is not entirely relevant for the energy performance of the building because this consumption may vary depending on the lifestyle of the occupants, appliances installed in the house and so on.

Currently, the studied passive house does not meet the standard imposed by the Passive House Institute in terms of energy consumption for heating and cooling but is a promising experiment for further development in the field. One of the reasons for higher than expected energy consumption for heating and cooling is the fact that the other apartment of the duplex was not inhabited or heated during the monitoring year. Therefore, heat losses occurred through the wall that separates the two apartments which was not sufficiently insulated. An extremely necessary upgrade of the house is the mounting of shadowing elements for the windows, in other to avoid overheating during the summer. Also, in winter days with very low minimum temperatures, the air water heat pump did not functioned properly, registering higher energy consumption. Nevertheless, the house ensures great thermal comfort achieved through well-insulated envelope elements, qualitative windows and an adequate ventilation system with heat recovery.

AKNOWLEDGEMENTS

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Post Occupancy Evaluation of University Eco Residences: A Case Study of Student Accommodation at Lancaster, UK

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ABSTRACT: Energy-efficient refurbishment of existing housing and reducing carbon emissions from the UK housing stock are vital for contemporary architecture in order to tackle the challenges facing the future of sustainable housing in the UK. Post occupancy evaluation of buildings based on a series of monitoring programmes have been undertaken in the newly constructed residences, looking at both operational consumption and specification of energy balance, providing approaches to determining energy saving requirements for the existing buildings as well as valuable experiences for new designs of energy-efficient and ecological buildings. The paper presents a summary of two-year period monitoring of indoor environment in the eco student residences located within the campus of Lancaster University in England, UK. The findings of the long term post occupancy monitoring programme have provided results showing the estimation of energy saving potentials and further improvements for tackling overheating problems in particular.

1 INTRODUCTION

1.1 *University Partnerships Programme*

The universities relationship with University Partnerships Programme (UPP) in the United Kingdom has been developed since 2002. The partnership has brought design and construction of new student residences with energy efficient and environmental performance (UPP, 2013). UPP's Eco Residences' construction model has been developed in collaboration with Dr. Avi Friedman, Professor of Architecture & Director of the Affordable Housing Programme of McGill University, Montreal in Canada (Friedman, 2013). The residential complex is considered as a sustainable student accommodation. The Eco Residences received a BREEAM Excellent rating in 2008, and is the first replicable, scalable model of its kind in the Higher Education (HE) sector. These Eco Residences can be found at Lancaster University, Leeds Metropolitan University and University of Kent sites, and there is ongoing developments at the University of Exeter and King's College in London (UPP, 2013).

1.2 *Residences at the University of Lancaster*

There are two types of new residences at the campus of the University of Lancaster (see Figure 1), townhouse blocks and cluster flats (see Figure 2). The townhouse block provides large open plan living space at ground floor level, with direct access to an external paved area and landscaped areas. The townhouse block accommodates up to 12 students, with a large shared kitchen/dining space at ground floor level. Each floor above has four bedrooms and two shower/toilet facilities. The townhouses are arranged as a terrace of units, with each unit being approximately 6 metres wide and 12 metres deep and four storeys high (see Figure 3). This facilitates the floor being designed to span across the unit, in turn eliminating the need for internal load bearing walls. This allows for the accommodation to be potentially reconfigured over time.

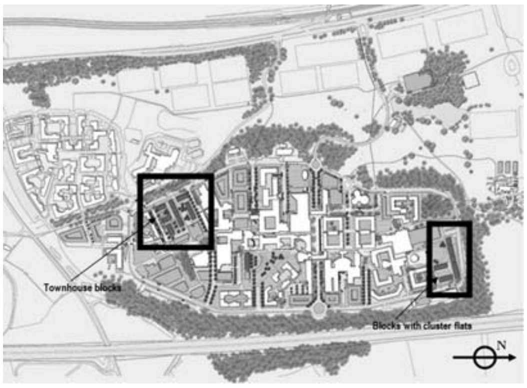

Figure 1. Lancaster University campus map with new residential units shown in black rectangles (UPP, 2013).

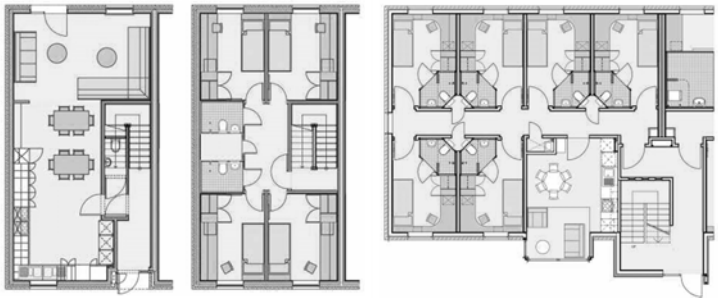

Figure 2. Townhouse block; ground and first floors (left) - Cluster flat; ground floor plan (right) of student Eco Residences at Lancaster University (UPP, 2013).

Figure 3. Student Eco Residences (townhouses block) at Lancaster University campus.

The cluster flat provides accommodation in six en-suite bedrooms with a kitchen/dining living space. Each flat is constructed of rectangular blocks of approximately 24 metres long and 12 metres deep, with central staircases serving two flats per floor of four storeys. The floors span from the external wall to the central corridors, allowing for easy reconfiguration. The exterior consists of brickwork at low level areas, with cement cladding and cedar cladding panels at higher levels. High insulation standards and a high degree of airtightness created a very energy efficient envelope. A section through the external wall and floor junction is in detail for both townhouse blocks and cluster flats presented in Figure 4.

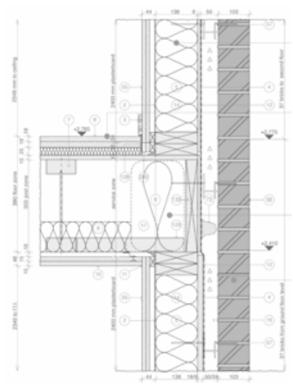

Figure 4. Section through the external wall and floor junction (UPP, 2013).

Each room is equipped with a radiator, controlled by a thermostatic radiator valve and gas condensing boiler. Low energy electrical fittings are used throughout and communal areas have detectors ensure that lights are switched off when spaces are unoccupied. In the study rooms, mini circuit breakers prevent unexpected use of high wattage device. Mechanical ventilation with heat recovery system (MVHR) operates on the extract ventilation serving the shower, washbasin and toilet facilities, providing warm air into the internal circulation areas (UPP, 2013).

Solar thermal roof panels in the south facing blocks of townhouses and cluster flats reduce demand on gas fired boilers in the hot water system. Low flow rate fittings have been installed to wash basins and showers, and toilet systems are dual flush. A sustainable urban drainage solution with on-site retention of surface water discharge has been adopted. An each townhouse and block of flats is equipped with a Building Management System (BMS) which constantly monitors the current consumption of gas, water and electricity and this information is accessible to students over the internet.

Akihiro Yamagishi et al. (1993) investigated the indoor environment and the post occupancy evaluation in an office environment from the viewpoint of interaction between physical environment and the human responses. The field survey has been conducted over a year. It was found that measured thermal conditions are on the edge of the ASHRAE comfort envelope in summer and in the neighbourhood of the lower dry limit of the envelope in spring (ASHRAE, 2013). Average luminance level represented 700-1200 Lux in the new building, in contrast with less than 300 Lux in the existing building (Yamagishi et al, 1993). This demonstrates the importance of conducting Post Occupancy Evaluation (POE) in order to assess the building performance in use and informs design of new prototypes, and therefore in this study POE has been carried out for better understanding of the newly constructed eco student residences located within the campus of Lancaster University in the UK for future developments. The POE studies are also useful for checking building designs against the accepted standards such as the guidelines specified by the Chartered Institution of Building Services Engineers (CIBSE) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

2 POST OCCUPANCY EVALUATION OF LANCASTER ECO RESIDENCES

2.1 *Temperature, relative humidity and illuminance*

The building residential complex has been monitored through a post occupancy evaluation programme investigating indoor environments of the Eco Residences (Altan, 2009), and the data sets have been analysed to show the following attributes:

- Indoor temperature, relative humidity and illuminance levels; daily profile in graphs.
- Maximum, minimum and mean indoor air temperatures and relative humidity levels (week days and weekends).
- Number of hours in a day when temperatures lie in specific temperature bands.

The example of characteristic outdoor climatic conditions in Lancaster between December 2008 and January 2009 is presented in the following Table 1.

Table 1. An example of external weather data set: Outdoor temperatures and relative humidity levels from monitoring measurements in Lancaster during December 2008 and January 2009 (Lancaster University, 2010).

December 2008	1	2	3	4	5	6	7	8	9
Average temperature	-0.1°C	1.5°C	1.2°C	4.1°C	4.3°C	2.8°C	2.6°C	5.9°C	2.0°C
Average relative humidity	57 %	80 %	73 %	83 %	76 %	66 %	74 %	85 %	71 %
December 2008	10	11	12	13	14	15	17	18	19
Average temperature	1.7°C	1.6°C	4.5°C	6.4°C	4.1°C	2.7°C	6.6°C	9.3°C	7.3°C
Average relative humidity	68 %	76 %	83 %	91 %	84 %	78 %	75 %	76 %	76 %
December 2008	20	21	22	23	24	25	26	27	28
Average temperature	9.0°C	10.7°C	9.8°C	8.0°C	6.9°C	7.8°C	5.7°C	3.1°C	3.8°C
Average relative humidity	75 %	86 %	92 %	92 %	84 %	82 %	64 %	57 %	59 %
December 2008	29	30	31					December Average	
Average temperature	2.1°C	0°C	-2.3°C					4.4°C	
Average relative humidity	59 %	69 %	80 %					76 %	
January 2009	4	5	6	7	8	12	13	14	15
Average temperature	2.3°C	1.2°C	-0.8°C	3°C	4.5°C	9.4°C	6.6°C	5.0°C	7.9°C
Average relative humidity	59 %	55 %	50 %	82 %	94 %	89 %	91 %	82 %	78 %
January 2009	16	17	18	19	20	21	22	23	24
Average temperature	7.9°C	7.7°C	5.4°C	3.8°C	5.0°C	4.3°C	6.6°C	4.7°C	3.7°C
Average relative humidity	79 %	70 %	61 %	77 %	70 %	81 %	71 %	78 %	75 %
January 2009	25	26	27	28	29	30	31	January Average	
Average temperature	6.3°C	5.5°C	6.3°C	5.9°C	6.6°C	6.6°C	4.8°C	5.2°C	
Average relative humidity	68 %	76 %	80 %	95 %	71 %	55 %	48 %	73 %	

Temperature and relative humidity levels within an indoor environment will vary with the time of year and the conditions of physical indoor environment. The data sets collected from the indoor monitoring equipment were statistically analysed to investigate the condition of indoor air temperature (°C) and relative humidity (%) profiles.

The post occupancy data analysis shown below indicates the spread in internal room temperatures as well as the weekly/hourly average temperatures and humidity levels for the specific rooms monitored. In the cluster block flats, location of the monitoring sensors in rooms are shown in Figure 5 and the results of the investigation are presented in Figure 6.

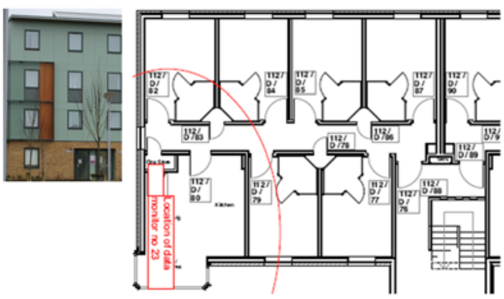

Figure 5. Location of the monitoring sensors installed in the selected cluster flats block (112).

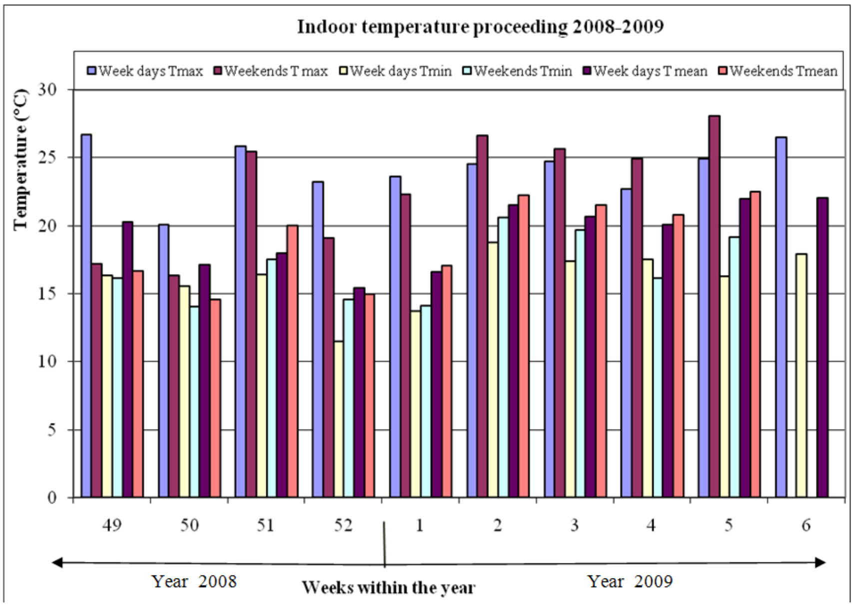

Figure 6. Cluster flats block 112, room D80 temperature profile.

As shown in Figure 6, average maximum (T_{max}), minimum (T_{min}) and mean (T_{mean}) temperatures have been determined for week days and weekends of the year 2008 end and the year 2009 beginning. The results of POE from monitoring the room (D80) are as follows:

– High indoor temperatures (even during cold days), for example: Week 2 on 17th January 2009, the external maximum temperature was 7.7°C which would be regarded as not being particularly high, however the internal temperature reached to 25°C or 26°C for about 7 hours. One reason for this could be that it was a sunny day, which further explains when the weather becomes warmer a significant overheating can be expected to occur.
– Maximum of indoor air temperature was reaching over 26°C in the first part of December. Generally the indoor thermal occupants' comfort is considered between 18°C and 23°C in the UK (CIBSE, 2006a); however for short time periods temperatures of up to 26°C or 27°C can be acceptable. Generally a building space could be regarded as overheated if its indoor temperature is 27°C or above for a two-hour consecutive period (CIBSE, 2010). Normally in office indoor environments if an overheating period lasts more than about 10% to 15% of the office working hour, thermal discomfort is considered (CIBSE, 2006a; CIBSE, 2006b).

The post occupancy monitoring data analyses have shown a potential overheating problem in the investigated area of cluster block flats and therefore as a result, it is suggested to install shading devices and activate them during intensive solar shining day periods. The evaluation of the townhouse blocks were also carried out and the location of the monitoring sensors are shown in Figure 7. There is an example of weekly indoor temperature frequencies where an overheating problem is presented. Even during the first three weeks of January 2009, the indoor temperature inside of the investigated room was greater than 25°C on many days with high frequency (see Figure 8). Figure 9 also presents frequency of indoor temperature bands during the first two weeks of January 2009 in the selected townhouses block (101).

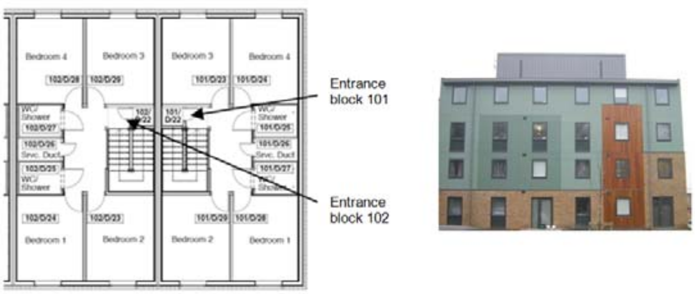

Figure 7. Location of monitoring sensors in the selected townhouses block (101 and 102).

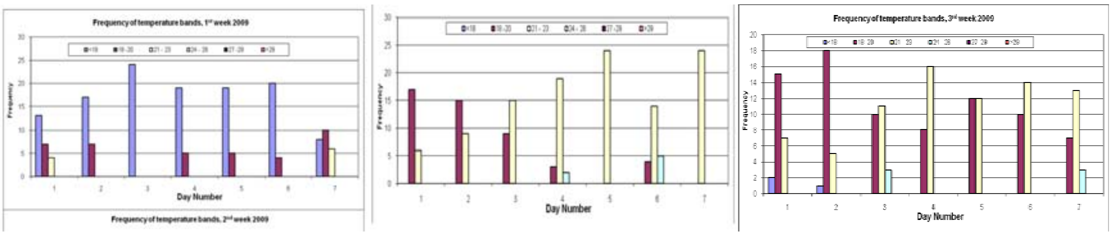

Figure 8. Frequency of indoor temperature bands during the first three weeks of January 2009 in the selected cluster flat (kitchen).

The facility rooms in Eco Residences such as shower rooms and toilets were also monitored between 17th April and 13th May 2008 periods. Such rooms are located in townhouses block (101 and 102) on all floor levels. Air temperature profiles within shower rooms in townhouses 101 and 102 monitored during April and May 2009 are presented in Figure 9.

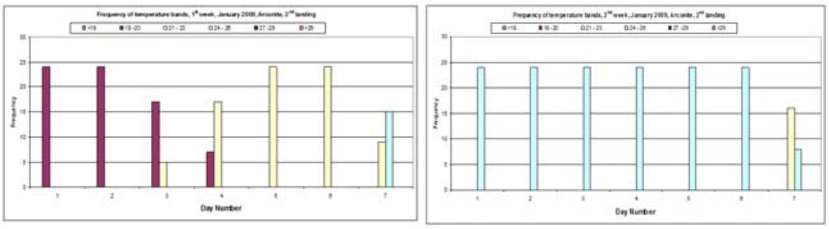

Figure 9. Frequency of indoor temperature bands during the first two weeks of January 2009 in the selected townhouses block, second floor, landing area.

In addition, relative humidity and indoor illuminance levels were monitored during the same periods (see Figures 11 and 12). As a result, there is an example of high air temperature rise at about 2 p.m. in a daily profile in the investigated facility rooms. The air temperatures reached to their peaks at about 3 p.m. and the temperature rise is suspected to be caused by the solar radiation transmitted through the bedroom windows. Morning and lunchtime solar gains may have highly influenced the early afternoon air temperature rise. On the other hand, the illuminance levels were also monitored in the facility rooms in order to determine the amount of time artificial lighting was in use (see Figure 10).

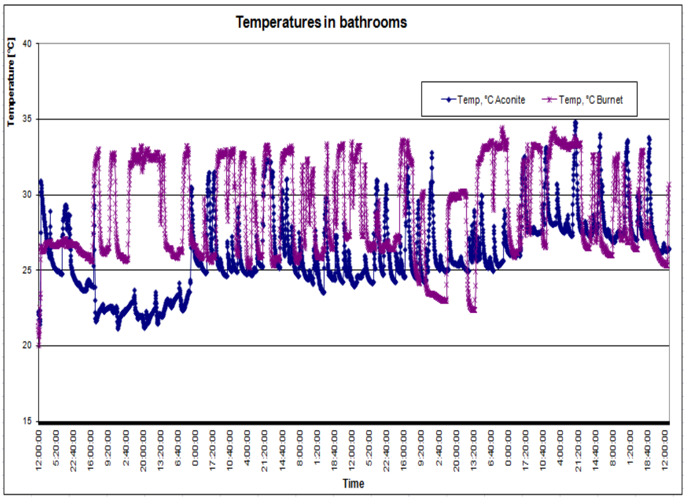

Figure 10. Temperature profile within bathrooms in the selected townhouses block between April and May 2009.

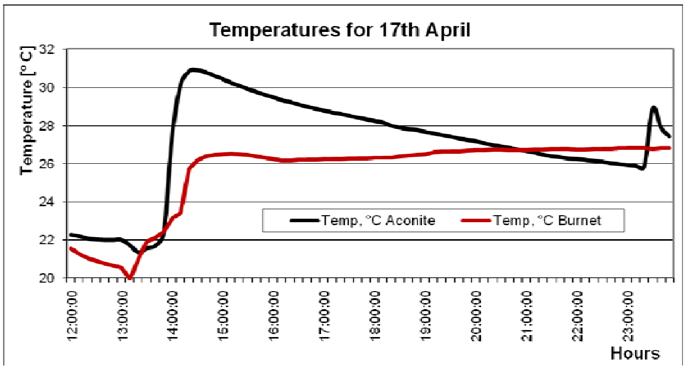

Figure 11. An example of a daily temperature profile on 17th April 2008.

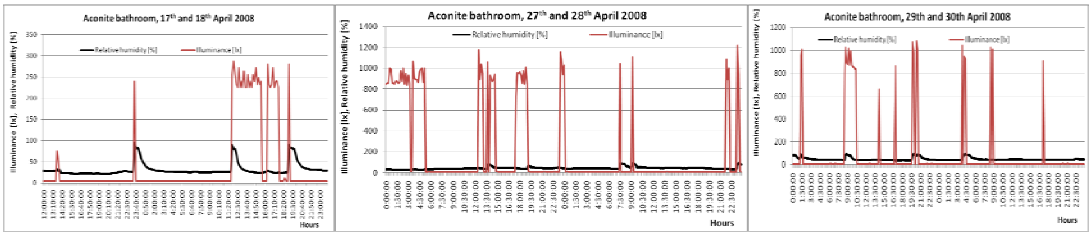

Figure 12. Findings of the illuminance and relative humidity levels in a bathroom in one of the selected townhouses' block monitored during April 2008.

The daily indoor air relative humidity with respect to bathroom illuminance levels are shown in above graphs. This has occurred due to shower usage during the certain parts of a day, for example between 11:30 a.m. and 12 p.m. on 17th April 2008 and between 11:20 a.m. and 19:30 p.m. (date missing) with short breaks. The remaining period, the relative humidity profile monitored is in relatively steady state.

The average values of indoor air temperatures and relative humidity levels in Aconite block's (101) facility rooms are determined from the data recorded in April and May 2008 and the measurements are as follows:

– Average indoor temperature 25.97°C.
– Average relative humidity 45.31%.

There is a clear usage of artificial lighting in shower rooms as well as frequent increase of illuminance and relative humidity levels, for example:

– Between 13:20 p.m. and 14:00 p.m. on 17th March.
– Between 23:00 p.m. on 17th March and 1:00 a.m. on the following day.
– Between 12:00 p.m. and 20:00 p.m. on 18th March, etc.

The most frequent increase of illuminance and relative humidity levels are during lunch hours, in the evenings and again during night times.

3 CONCLUSION

In order to ensure a low carbon footprint, the Eco Residence is built off-site from sustainably sourced timber and features high levels of insulation, airtightness and innovative MHRV systems. By using timber frames, sourced from sustainable, managed forests and manufactured off-site, UPP minimises waste, reducing the carbon footprint of each build by 30%. To ensure continuous sustainability, a range of energy and water saving technologies is implemented, including roof mounted solar thermal panels to preheat hot water, lighting controlled by Passive Infra-Red (PIR) units, enhanced airtightness and better insulation levels, together with recycling facilities as standard. Further studies are continuing to look at these measures as part of a wider POE.

The long term monitoring of the student residential complex (Eco Residences) for indoor temperature, relative humidity and illuminance levels as part of a post occupancy evaluation programme were completed throughout the design stages with progressive architectural concept based on idea of energy efficient and sustainable dwellings. Infrared imaging survey of the winter service of the buildings' facades also showed that the building envelopes are sufficiently insulated without constructional failures and excessive thermal bridges. The main drawbacks of the buildings' facades design are under eaves at the top floor which could have been better thermally insulated and also in the position of ventilation openings in facades. The main problem of the newly constructed residential complex might be overheating in some of its building blocks. This problem should be rectified by the additional movable shading elements which could be activated in a season of very high and intensive solar loading and again deactivated during overcast sky conditions to allow sufficient daylighting into the residential spaces.

4 ACKNOWLEDGEMENTS

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Computational modelling of the thermal behaviour of an ETFE cushion using IES

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ABSTRACT: Ethylene Tetrafluoroethylene (ETFE) membrane is a recent popular option for the building industry as a sustainable alternative to glazing; typically assembled into cushions to retain structural stability and improve thermal resistance. ETFE is often absent from material libraries found in energy simulation tools, frequently requiring designers to use glass material properties in substitution, potentially leading to errors when calculating the energy consumption of a building employing ETFE cushions. This study investigates the differences in performance between glass and ETFE; specifically in relation to energy used for space heating.
Integrated Environmental Solutions (IES) is an engineering and environmental performance software tool used to estimate the energy performance of buildings. This study uses experimental data combined with IES simulations to determine the energy consumption of a simple building model. The results of this research provide information to create a profile for ETFE to be used with IES or similar simulation software.

1 INTRODUCTION

Ethylene TetraFluoroEthylene (ETFE) is a melt-processible fluoropolymer, belonging to the sub-category of polymer materials called thermoplastics (Kopeliovich, 2011). The material is typically extruded in the form of a membrane which is then assembled to cushions of two to five layers and welded around the edges (LeCuyer *et al.*, 2008). Air valves are fixed on the cushions. The valves are connected to an air pump system that provides the cushion with a constant air pressure of 250-700 Pa to obtain its structural stability and thermal resistance (Robinson-Gayle *et al.*, 2001).

ETFE cushions have been examined in the pursuit of a replacement to glazing, as a solution to the downsides that are associated with its use; such as its fragility, weight and behaviour towards light and heat transmission (Clarke *et al.*, 1998; Robinson-Gayle *et al.*, 2001). If uncoated, glass presents high transmission of near Infra-Red radiation, which leads to an increase of solar gain and a consequent need for cooling in warm conditions. At the same time, uncoated glass presents a low reflectance of far Infra-Red radiation which leads to an increase in heat loss and a related rise in heating requirements during cold weather (Brauer, 1999). The excessive use of glazing also increases the embodied energy and the cost of a supporting structure. Furthermore, the geometry of the building is often an obstacle to the use of glass.

The structural benefits of ETFE cushions in comparison to glass can be summarised to its lower weight, the ability to reach larger spans and freedom of form. Moreover, ETFE membranes are insensitive to deformations of the primary structure, UV resistant, have low maintenance costs such as cleaning and low hazard potential in the event of a fire, explosion or windstorm (Schween *et al.*, 2007).

For a typical thickness of 200 μm an a single ETFE film weighs below 3.5 kg per m^2; a much lighter weight than the glazing required covering the same area, therefore reducing the embodied energy of manufacturing and transport to 1% of that associated with single glazing. The lighter weight of the membrane also results to the requirement of a lighter supporting structure than that used in a glass structure, thus reducing cost and energy demands (LeCuyer *et al*., 2008; Robinson, 2005).

ETFE film is transparent to long-wave radiation. The transmission of long-wave radiation in the case of the cladding unit will depend on the temperatures of the glass panes and their surroundings. Depending on the orientation of the material in relation to the temperature difference between the interior and exterior, the occurring long-wave radiation flux will be inwards or outwards respectively (Poirazis *et al.,* 2010).

ETFE cushions cannot be treated like glass while performing an energy study on its thermal performance. At present there is no available information for the quantification of the long-wave radiation transmission through ETFE cushions (Poirazis *et al.,* 2010). A previous preliminary study by the authors aimed to amend this issue by using the results of an experimental study on the thermal response of a single ETFE membrane cladding unit, alongside a single glass pane cladding, exposed to the same external conditions and supported by the same internal condition regulating mechanism (Dimitriadou *et al*., 2012). The experiment was refined and repeated at a bigger scale, using a double layer ETFE cushion alongside a double pane glass unit. The present work uses Integrated Environmental Solutions (IES) to reproduce the experimental conditions and results. The result of this research is to determine the necessary adjustments that must be made and the factors to be taken into account when using IES to estimate the energy consumption of a building using one or more ETFE cushions as cladding.

2 EXPERIMENTATION

2.1 *Experimental setup*

The physical experiment took place using two insulated boxes covered by a two-layered inflated ETFE cushion and a double glazed unit respectively. Both boxes were exposed to the same external conditions. The measurements examined in this study were recorded between the 30th of February 2013 and the 06th of April 2013 under a variety of weather conditions. The structures were located on the roof of the Department of Architecture and Civil Engineering building at the University of Bath (51.38°N, 2.36°W), in Southwest England.

The boxes enclosed a volume of 900 mm height, width and length, with walls and floor made of a single layer of 100 mm PIR foam insulation. The assembly was held in place externally by a wooden frame and the edges were sealed with the use of insulating polyurethane spray foam. Thermal imaging was used to detect areas of excessive heat loss and enhance the insulation around these sensitive areas. Figure 1 and Figure 2 present the experimental setup.

Figure 1. Experimental set-up

Figure 2. The ETFE cushion (left) alongside the double glazed unit (right)

The ETFE cladding unit comprised of a two-layered cushion with dimensions of 900 mm by 900 mm. The cushion membrane had a thickness of 200 µm and the internal side of the cushion was covered by a reflective dotted silver frit. The ETFE unit was prefabricated and supplied by

Vector Foiltec and was inflated to 220 Pa using a Michelin 12250 12 v Digital Tyre Inflator Air Compressor. The glass cladding was comprised of an uncoated, un-toughened double glazed unit of 900 mm by 900 mm and a composition of 4 mm glass – 6 mm air gap – 4 mm glass.

A 100 mm Vent-Axia Silhouette Fan with shutters was used in each box to assist the controlled ventilation of the experimental unit and resolve condensation issues at a maximum extraction rate of 26 l/sec. The fans in both boxes were running continuously and maintained interior relative humidity levels below 60 % for both boxes. The air was extracted from the main box covered with the cladding material, introduced through ducts into auxiliary boxes that assisted in the drying of the air and then was re-introduced in the main box. The fans operated constantly, maintaining a steady interior environment.

The extracted air travelled through plastic ventilation tube of 100 mm diameter, enveloped in a 25 mm thick layer of sheep's wool insulation and surrounded by an external reflective flexible tube of 150 mm diameter. The tube system was connected in an air-tight manner to a separate external box constructed from 100 mm PIR rigid foam insulation holding 285 g of loose desiccant silica gel in each box. The silica gel was dried out prior to weighing and installment in the boxes. After being introduced to the desiccant boxes the same air is then re-entered to the experimental boxes to avoid heat loss through a fitted outlet with shutters.

Each box enclosed two tubular heaters of 655 mm length and 80 mm diameter, with a heating capacity of 120 Watt each. The energy consumed by the heaters was measured using Elster A100c electricity meters. Pulsed output was recorded using Grant SQ2010 Data Loggers. The number of pulses was recorded at 5 minute intervals.

Two K-type thermocouples were located on the North-facing wall and the cladding of each box to record surface temperatures. The surface temperatures were measured with the use of a Grant SQ800 Data Logger. Each box also housed air temperature, black bulb radiant temperature and humidity sensors monitoring interior conditions. Air temperature and black bulb radiant temperature were recorded using a Grant SQ2010 Data Logger, whereas humidity was measured with the use of a Tinytag Data Logger.

2.2 *Calibration*

Prior to the conduction of the main experiment, the calibration of the boxes took place with both experimental units covered by a 12 mm plywood sheet, concealed with a layer of white, waterproof, non-reflective paint. The calibration process took place throughout the period between the 10th of January and the 18th of February 2013. Both boxes were exposed to the same shortwave and long-wave radiation and external air temperature conditions and bared the same heating, ventilation and recording equipment, placed in the same location.

The box that would later be covered with the ETFE cushion was situated on the South of the box that would later be covered with glass and was therefore more exposed to the prevailing winds of the area. This resulted to a greater heat loss and called for the use of adjustment coefficients on the measured data to match the trend describing the interior thermal conditions and the co-responding energy performance of the glass box. After the calibration of the measured results, the two boxes covered by wood presented an identical thermal behaviour and energy consumption, which allowed the following recordings under the ETFE cushion and the glass unit to be evaluated on a comparable basis.

2.3 *Weather file adaptation*

External air temperature was monitored in the same location of the experiment. Additionally, a Kipp & Zonen CMP3 pyranometer and a CGR3 pyrgeometer were used for the measurement of the corresponding incident shortwave and long-wave radiation. The pyranometer was adjusted to the geographic location of the 6 East building on the University of Bath campus and recorded both global (direct) and diffuse radiation. Furthermore, relative humidity, wind direction and velocity and barometric pressure were measured on the same location.

The local weather recordings were used to create a weather data file for use in the subsequent IES simulations. The direct normal radiation and cloud cover values were derived according to the IES-VE ApacheSim Calculation Methods (IES-VE, 2013; Kipp&Zonen, 2012).

3 IES MODELING

3.1 *Model setup*

This section describes the process that was followed for the representation of the physical model in a digital form. The material surface emissivity values were not the default ones corresponding to the used materials but were inserted manually, as the walls of the boxes were painted for protective purposes.

Regarding the implementation of the cladding units, the material properties for the glass unit were taken by default by the IES library, with the exception of the surface emissivity which was considered low and was supplemented using the online database on glass properties provided by the Lawrence Berkeley National Laboratory (LBLN, 2013). The values used for the ETFE unit were taken from the Vector material properties sheet for Texlon©, the Teflon© material properties sheet by DuPont and personal communication with Vector Foiltec (DuPont, 2012; Vector, 2012; Vector, 2013). Table 1 presents a summary of the material properties used to describe both cladding materials.

Table 1. IES model – description of cladding.

	Glass unit			ETFE cushion		
	Clear float glass	Gas (air)	Clear float glass	ETFE membrane (outside layer, clear)	Gas (air)	ETFE membrane (inside layer, dot matrix 65 %)
Thickness (mm)	4	6	4	0.2	40	0.2
Conductivity (W/mK)	1.06		1.06	0.23		0.23
Convection coefficient (W/m²K)		4.16			2.613	
Resistance (m²K/W)		0.127			0.163	
Solar transmittance	0.82		0.82	0.911		0.54
Outside reflectance	0.07		0.07	0.08		0.33
Inside reflectance	0.07		0.07	0.08		0.34
Refractive index	1.526		1.526	1.4		1.4
Outside emissivity	0.92		0.92	0.82		0.81
Inside emissivity	0.92		0.92	0.82		0.57

The ETFE cushion could not be implemented as a curved surface and was therefore represented by two parallel flat surfaces. Furthermore, the distance between the two ETFE layers had to be increased to 400 mm in contrast to the 200 mm maximum distance of the actual cushion at the peak of its camber in order to reach the desired U-value for an ETFE cushion as it was specified by the Vector Texlon© material properties sheet (Vector, 2013).

ETFE membrane was essentially treated by IES as a double glazed unit with different properties. The U-value for the glass unit was 3.6 W/m²K alone and 4.0 W/m²K with the frame. The U-value for the ETFE cushion was 2.9 W/m²K alone and 3.3 W/m²K with the frame.

The function of the fans was not implemented in the IES model. Although useful for energy applications, the building simulation of indoor air movement through the use of simulation software such as IES is limited. For this reason, the simulation concerning the internal conditions of the experimental unit including the main box, the auxiliary ventilation box and the ducts is simplified and the thermal and energy calculations are performed considering the summary of the boxes and ducts as a uniform space in steady-state (Clarke, 2001). A simulation using Computational Fluid Dynamics (CFD) will be performed in the future to resolve this issue. In the present investigation, the energy performance presented will concern only the heating requirements of the space, excluding the energy consumed for the function of the fans.

3.2 *Considerations*

Regarding the design of the experimental units using IES, the ducts had to be represented in rectangular form as IES converts curved shapes into a series of flat plane surfaces. For the same reason the camber of the ETFE cushion could not be accurately represented. The simplification of the curved surface of an ETFE cushion to a flat plane has implications with regards to radiative heat transfer due to differences in view factors, since each point of the cushion surface is at a different orientation relative to the radiative source. However this simplification is expected to have little impact given the limited curvature of the ETFE cushion and future work aims to investigate more realistic geometry through finite element analysis methods.

3.3 *Model adjustment*

This section discusses the process followed to adapt the IES model to the physical model for the ETFE box. Air infiltration was added to the IES model as the physical model did not achieve complete airtightness. Energy consumption calculations were performed and the suitable amount of air infiltration was selected through trial and error in order to reach the correct model providing with a simulated energy performance that was a match to the real-life energy measurements. The selected amount of air infiltration required for both boxes was 2.0 l/s.

Air infiltrations of various levels were simulated until a best fit to the experimental data was achieved. A linear regression was performed for each simulation and the regression with the best fit was ultimately selected as the representative option. This process was first performed for the glass box, considering that all other properties of that box were already known. Using this as a basis, the same digital model of the box was then covered with the ETFE cushion, in which case an energy and internal condition simulation took place. The calculated results were compared to the real-life measurements.

4 RESULTS

4.1 *Physical experiment measurements*

The heaters enclosed in each box were set to maintain the internal air temperature at 19 °C. The total measured energy consumption due to heating of the ETFE box throughout the period under examination was 12.2 kWh, slightly lower than the equivalent 12.4 kWh recorded for the glass box.

The range of air temperatures recorded in the ETFE box varied between 18 and 50 °C and the range of radiant temperatures varied between 17 and 55 °C. At the same time, the range of measured air temperatures inside the glass box spread between 17 and 54 °C, whereas the measured radiant temperatures ranged between 17 and 62 °C.

The high measured internal temperature values were recorded under clear sky conditions with a high solar input, leading to overheating of the boxes as no cooling system was installed. Both boxes were steadily maintained at interior conditions close to the desired set point of 19 °C under cloudy skies during night and day for the periods of interest i.e. heating period.

The recorded lower measured air temperatures of the ETFE box can be associated to the better U-value of the cushion. The reflective properties of the silver dotted print on one of the layers of the ETFE cushion also assisted the effect of the insulating properties of the cushion on the maintenance of internal conditions. The lower measured radiant temperatures within the ETFE box under a clear sky can be justified through the transparent nature of the material towards long-wave radiation and the fact that the membrane allowed for heat to escape.

The ability of the IES model to accurately simulate the recorded energy consumption and internal measurements is discussed in the following section.

4.2 *IES model accuracy*

A linear regression analysis was performed for the measured and simulated energy data for the glass model, resulting to a bivariate correlation coefficient R of 0.98, indicating a strong relation of the dependent variable simulated energy consumption to the independent variable measured energy consumption. An error of 0.006 kWh resulted for the estimated energy consumption model.

A linear regression was also performed to examine the accuracy of the calculated air and radiant temperatures, in which case the correlation coefficients were 0.99 and 0.99 correspondingly, with an estimated error of -2.2 °C for the simulated air temperature and 1.5 °C for the simulated radiant temperature. A linear regression analysis was also performed for the ETFE model, resulting to a bivariate correlation coefficient of 0.98 and an error of 0.010 kWh. The correlation coefficients for air and radiant temperature were 0.99 and 0.99 and the estimated errors were -0.3 °C and 2.1 °C respectively.

The good correlation values suggest that IES was successful in providing an accurate model for the prediction of energy consumption and internal air and radiant temperature.

4.3 *Analysis*

The measured and simulated results were divided into two groups corresponding to clear sky and overcast sky weather data. The analysis regards only night-time data to avoid the effect of shortwave radiation and the consequent overheating of the boxes. A linear regression was performed to determine the relationship of the measured and the estimated energy consumption for each of these categories. Under a clear sky the correlation for the ETFE box simulation was 0.85 and for the glass box simulation it was 0.84, whereas under an overcast sky the corresponding correlations for ETFE and glass were 0.95 and 0.94 respectively. This indicates the ability of the design tool to calculate energy response more accurately under a cloudy sky rather than under a clear sky.

The level of accuracy of the energy consumption simulations can be considered equal for both materials. As the interest of this paper revolves around the modeling of an ETFE cushion, the analysis will focus on this roof material. Furthermore, since the simulation under an overcast sky presents very high correlation coefficients, the analysis will proceed concentrating on interpreting the simulation inaccuracy under a clear sky in particular.

The measured and simulated energy consumption is expressed relative to the difference between internal and external air temperature (Figure 3).

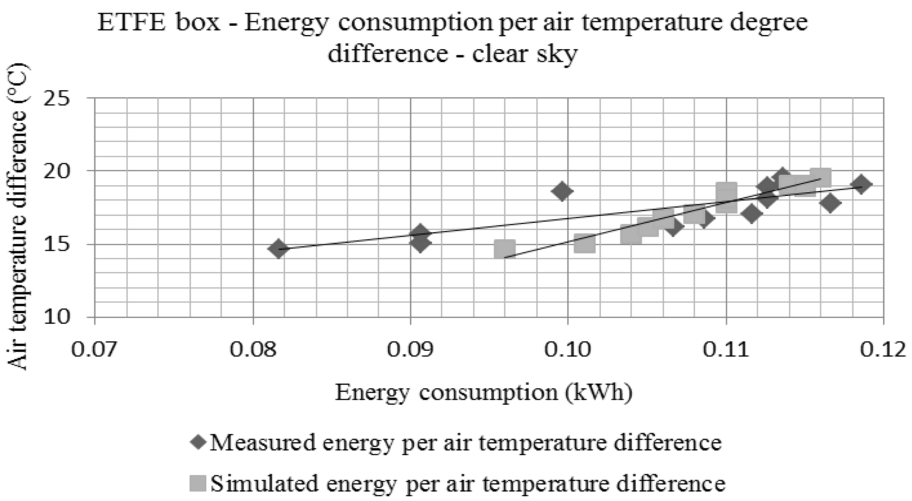

Figure 3. Energy consumption per air temperature degree difference under clear sky conditions.

The points where there was a noted significant deviation between measured and simulated energy per air temperature difference coincided with lower recorded radiant temperatures and the related lower sky emissivity, as well as lower relative humidity levels, which are features associated with a very clear sky. This suggests that the IES model failed to take into consideration the low clear night sky temperature; which would affect the estimation of the amount of heat escaping the box in the absence of clouds and solar input. This fact could be related to the uncertainty accompanying a weather data file, since it only takes into account a certain number of aspects of the sky nature over hourly time intervals.

5 CONCLUSIONS

Ethylene Tetrafluoroethylene (ETFE) membrane is an innovative, sustainable substitute to glazing. The benefits that accompany the use of ETFE cushions include good energy saving potential due to their daylight transmittance, low embodied energy, light weight and thermal behaviour that is comparable to that of an average double glazed unit. Thermal performance data for ETFE, either in the form of a single membrane or a cushion, is not commonly found in material libraries that are employed by energy design programs, leading designers to use glass material properties as the default option. This leads to errors when calculating the energy consumption of a building employing ETFE cushions, which is what this study aimed to amend; particularly in the case of the energy related to space heating. The results of this work should be useful to designers wishing to evaluate ETFE cushions as an option in the attempt to optimise the energy profile of a building and minimise risk and error.

The proprietary thermal modelling tool IES-ve showed good agreement between simulated and experimentally measured energy performance but further work is required to address discrepancies of modeling under different sky types and to ascertain the effect of simplification of the cushion geometry.

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Natural Fibre Reinforced Earth and Lime Based Mortars

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ABSTRACT: The present research work was developed with the main objective of enhancing the basic characteristics of earth and lime plastering mortars, in particular taking into account the shrinkage effect of clays in order to avoid cracking. For this purpose one has studied: a standard mortar made of earth and lime, without the addition of fibres; the incorporation of several types of fibres in the standard mortar. The addition of natural fibres (banana, coconut, sisal) was tested and, in order to compare its results, the incorporation of synthetic fibres (polypropylene) was also tested. Due to the large range of earth clay contents and types of clay, with distinct behaviours, one has performed expeditious tests in order to characterize the clays. To evaluate the performance of the incorporated fibres in the mortars one has developed laboratorial tests to achieve the most relevant properties: workability; mechanical behaviour; water behaviour; and susceptibility to cracking.

1 INTRODUCTION

As a result of the increasing demand for a sustainable architecture, the interest in earth building, as well as in earth and lime based mortars have recently grown. Therefore, these mortars have been studied regarding its use both in renovating old buildings and in new ones made with earthen walls (Gomes et al 2012 and Morton & Little 2007) or in straw bale walls (Taylor et al 2006).

The main advantages of using these mortars are: i) higher compatibility with old materials than cement based mortars (Gomes et al 2012); ii) less energy consumption during its manufacture (Taylor et al 2006); iii) and greater healthy building interiors similarly to what happens in earth building (Morton 2008).

An earthen mortar consists of a mixture of earth with fine grains and water. The cohesion of these mortars is essentially assured by the clay fraction present in the earth material but also due to additives, fibres and fillers eventually added to the mortar to improve their characteristics. It is recommended that earthen mortars should be produced with adequate additives, such as crushed straw or other fibrous plants. Other additives may be added as lime, gypsum, artificial or natural pozzolans, cement, resins, biopolymers, etc (Dachverband Lehm e.V. 2008). The added materials should be selected in such a way that the properties of the obtained mortar meet the requirements set out according to the *Lehmbau Regeln* (Rules governing building with earth) from German Association for Building with Earth (Dachverband Lehm e.V. 2008).

The properties of earthen mortars depend essentially on bonding strength of earth material, provided by the amount and type of the existing clay. It is recommended to use a soil which clay content will not be very poor and it must be free of stones and with grains dimensions lesser than 5 mm (Dachverband Lehm e.V. 2008). The variety of clay minerals present in the soil also influences directly the soil properties and consequently the obtained mortars. These minerals result in different levels of water retention, plasticity, water dispersion and expandability of soil.

The lime may be added to clay-rich soils, once it provides an increase of mechanical strengths and subsequently its durability (Houben 2008). However, it is not possible to advise a suitable mixture because the amount of reactive clay can differ considerably. Holmes and Wingate (Morton & Little 2007) have suggested an optimal content of 10% of clay and a lime proportion between 3% and 10%. However, these authors warn that for proportions inferior to 5% the compressive strength can be reduced instead of increased (Morton & Little 2007).

Regarding the use of lime either in paste or in powder, in a research study about in-situ applications of lime mortars, the respective laboratory tests do not differ significantly in the resistances or capillarity of mortars made with lime in paste or in powder form (Margalha, et Al 2006). However, the lime paste present some advantages compared to lime powder: do not lose quality with the storage, because the water reduces the carbonation process; improves the workability; and reduces the later cracking of the dry mortars (verified with the use of lime pastes of old hydration) (Margalha, et Al 2006).

The use of fibres in earthen mortars is mainly associated with the possibility of shrinkage cracking reduction**.** However, there are many types of fibres, with different physical properties, and this may affect how they interact within clay and lime materials (Morton & Little 2007).

The purpose of this research study was to propose a possible solution for earth walls rendering and evaluate the main properties of earth and lime based mortars with addition of natural fibres (sisal, banana and coconut) and synthetic fibres of polypropylene. To evaluate the performance of the incorporated fibres in the mortars one has developed laboratorial tests to achieve the most relevant properties: workability; mechanical behaviour; water behaviour; and susceptibility to cracking. The obtained results will be presented and analysed.

2 REQUIREMENTS FOR EARTH BASED PLASTERING/RENDERING MORTARS

A research about reference values for essential properties of earth based plastering/rendering mortars has been conducted and the following recommendations were found.

In Lehmbau Regeln it is mentioned that the minimum compressive strength for interior plastering should be ≥1,5 MPa, corresponding to Category CSII (compressive strength between 1,5 to 5,0 N/mm^2 according to EN 998-1) (Dachverband Lehm e.V. 2008). Minke & Ziegert (2008) cited other requirements for plastering mortars, these are listed in Table 1.

Table 1. Minimum requirements for the compressive strength of clay mortar in relation to their intended use (Minke & Ziegert 2008).

Type of use	Compressive strength (MPa)	Pull-out strength (MPa)
Secondary spaces	≥0,5	-
Clay plaster intended for subsequent surface stabilizing in rooms for general use, e.g. living and work rooms in single and multi-occupancy houses	≥1,0	≥0,03
Clay plaster as base for finishing plaster, coating, and wallpapers	≥1,5	≥0,03

Regarding the replacement or renewal plastering, Veiga (2003) mentions some values for properties of plastering for irregular masonry walls, based on the acquired experience (see table 2). In this case, the requirement for compressive strength is included in class CSI, as defined in the standard EN 998-1.

Table 2. Minimum requirements for different properties (Veiga 2003).

Mortar	Tensile strength (MPa)	Compressive strength (MPa)	Pull-out strength (MPa)	Capillarity coefficient, C (kg/m^2.min^{0,5})
Rendering mortar	0,2–0,7	0,4–2,5	0,1–0,3 or cohesive	1≤C≤1,5
Plastering mortar	0,2–0,7	0,4–2,5	rupture by the plaster	1≤C≤1,5

3 SELECTED MATERIALS AND PERFORMED MIXTURES

3.1 *Selected materials*

The selected soil was collected in a region at the centre of Portugal (near Figueira da Foz) and before its use was submitted to manual crushing. For soil characterization sieve and sedimentation analysis were performed, as well as the checking of clay type present in the soil.
Commercial available natural river sand was added, whose particle size distribution is medium (0,063 mm - 4 mm in accordance with the standard EN 933-1). This sand addition has the purpose of reducing the high shrinkage, once the soil has a large amount of fine particles (clay and silt), around 39% by weight, as can be seen in Figure 1. Through the sedimentation analysis of the fine sample, it was verified that approximately 47% is clay and 53% is silt.

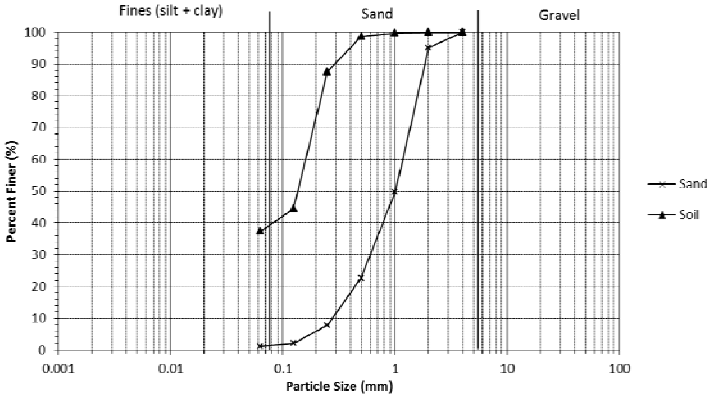

Figure 1. Particle size distribution of soil and sand used.

In order to confirm the clay type in the used soil the ”*Emerson*” test described by Houben & Guillaud (1989) was performed. According to this test, the presence of kaolinite and montmorillonite in equal proportions was verified.

The used binder added was lime paste from a Portuguese company (Fradical) which may be classified as a CL90 one according to standard EN 459-1, and with a density of 1300 kg/m^3 (Fradical 2006).

The used fibres (sisal, banana and coconut or coir) are from Brazil, which are classified as natural, organic, of plant origin. Sisal fibres are originated from the sisal leaves, coconut fibres from the fruit of coconut palm and banana fibres from the stem of banana tree. The fibres were cut in pieces of 20 mm in length approximately. However, this length was more difficult to achieve with coconut fibres, because they were jumbled. The physical and mechanical properties can be seen in Tables 3 and 4.

Table 3. Physical properties (Carvalho 2012, Vimaplás 2009, Jalali & Torgal 2010).

Fibre	Diameter (μm)	Specific mass (kg/m^3)	Linear mass (Tex) (g/km)	Water absorption after 5 min (%)	Water absorption when saturated (%)
Sisal	100–300	1260	26–45	67–92	190–250
Banana	150	1500	10–30	-	407
Coconut (coir)	40–400	1390–1520	16–35	22–38	85–135
Polypropylene	38	-	-	-	-

Table 4. Mechanical properties of fibres (Carvalho 2012, Vimaplás 2009).

Fibre	Tensile strength (MPa)	Young’s modulus (GPa)	Maximum force (N)	Elongation in maximum force (mm)
Sisal	324–329	19	12,4–18,1	3,0–3,5
Banana	700–800	-	2,2–4,7	2,3–2,5
Coconut (coir)	95–134	2,5–4,5	2,6–5,1	11,4–14,0
Polypropylene	340–400	3,5–4	-	-

3.2 *Performed mixtures*

The mortars were prepared in the proportion of 1:1,5:3 (lime: soil: sand) and with an addition of 0,24% of fibres (by weight of dry mixture). The amount of water added was determined through trial mixtures according to a required consistency of about 150 mm (flow test, see table 5). The mixtures were performed with the main objective of maintaining the water/binder ratio as low as possible in order to improve the performance of the plastering and considering that the average percentage of water contained in the lime paste (after drying at 100ºC) was 57%.

The process of mixing adopted was manual and it followed a specific methodology: i) homogenization of soil with sand; ii) introduction of lime; iii) manual mixing with water addition to attain required consistency (according to the result of the performed flow test); iv) and finally the addition and mixing of fibres in the paste.

The different mixtures performed are called as EM (earthen mortar) in the tables and graphics of this paper and each associated number corresponds to a mixture (e.g. EM0-Without fibres).

4 METHODOLOGY

The experimental research that has been carried out has involved the mortars characterization in the fresh state, through the consistency determination by flow test, as well as the characterization in dry state by evaluation of: i) susceptibility to cracking; ii) water absorption by capillarity; iii) drying; iv) mechanical resistance (flexural tensile strength and compressive strength); v) and adherence to the support by pull out tests. It should be noted that some tests are not easy applicable to earthen mortars due to the slow hardening, low mechanical resistance and susceptibility to water action, which forced to adapt the test procedures.

The flow test was performed according to European standard EN 1015-3 (1999). The consistency considered as adequate for the mortars was fixed in a flow of 150 ± 10 mm.

The flexural tensile strength and compressive strength tests were performed according to EN 1015-11 (1999). Concerning the specimen's manufacture, some difficulty in the use of compacting with pestle (prescribed by the standard) was verified because of the presence of the incorporated fibres. Therefore, mechanical compacting equipment prescribed by the standard EN 196-1, with 25 shocks by each layer was employed. The maturing conditions for mortars (of cement, lime and others) require a moist environment during 7 days, with the specimen 2 or 5 days inside the moulds. However, in this case, the specimens did not harden enough until 5 days and the specimens were kept in the moulds for 7 days. After, the specimens were removed from the moulds and were placed in a conditioned room (at 20 ± 2ºC and 65 ± 5% RH) until 21 days of age. In the compressive strength test, the halves of the specimens resulting from the flexural strength test were used.

The evaluation of the susceptibility to cracking consists of the application of a mortar sample on one side of a ceramic brick (dimensions of 30×20×15 cm^3), checking over time, through visual observation, the appearance, or not, of cracks. The mortar was applied in one layer with a maximum thickness of 1.5 cm and these bricks were kept in normal room conditions, with average temperature of 16,6 ºC and relative humidity of 62,3% for 28 days.

The water absorption by capillarity tests was performed according to EN 1015-18 (CEN, 2002). For this purpose, two specimens of each mixture were used, which were sideways waterproofed at 28 days of age and tested. The test was made subjecting the broken surfaces of the specimens on contact with water (10 mm above the specimen base).

The drying tests were performed using the specimens after the water absorption by capillarity test, with the underside sealed by a polyethylene film and placed in a conditioned room (at 20 ± 2ºC and 60 ± 5% RH).

The pull out tests were performed according to EN 1015-12 (2000) in five samples obtained from the mortar applied on the ceramic bricks for evaluation of cracking.

5 OBTAINED RESULTS AND DISCUSSION

5.1 *Consistency determination by flow test*

Table 5 shows the water added to the mixtures, the corresponding water/dry material ratio and the obtained flow. As it can be seen, the mixture made with sisal present a higher value of added water. This value can be explained due to the high water absorption of sisal, but also because of its high stiffness which makes the flow of the plaster more difficult. It is also important to notice that the incorporation of banana, coconut and polypropylene fibres didn't seem to increase significantly the water demand.

Table 5. Ratio of water/dry material and the respectively results of flow test.

Mixtures	Water added (ml)	Ratio of water*/dry material (%)	Flow (mm)
EM0 - Without fibres	350	19,91	160
EM1 - Sisal	465	23,04	150
EM2 - Banana	350	19,91	150
EM3 - Coconut	360	20,18	150
EM4 - Polypropylene	350	19,91	150

* including the water present in lime paste.

5.2 *Mechanical strength*

The results of flexural tensile strength and compressive strength are presented in Figure 2. It can be noted that the addition of natural and synthetic fibres have increased the resistances compared to the mixture without fibres, especially in compressive strength. The increase was higher for coconut fibres, about 70% and 44% in compressive and flexural strength respectively.

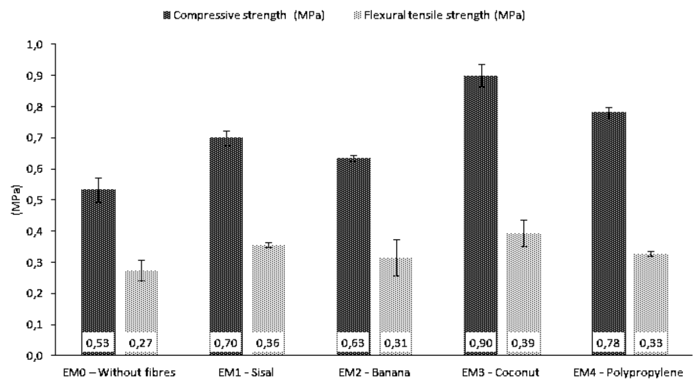

Figure 2. Flexural tensile and compressive strength with standard deviation.

5.3 *Susceptibility to cracking*

For the evaluation of susceptibility to cracking, one has applied the selected mixtures on ceramic bricks, with the purpose of its visual observation along time. One has only detected the appearance of cracks in the mortars made without fibres (EM0) and in the mortars with polypropylene fibres (EM4). In Figure 3 one can see some large cracks in the EM0 mixture and the highest number of cracks in the mixture EM4, although these are of much lesser length and thickness.

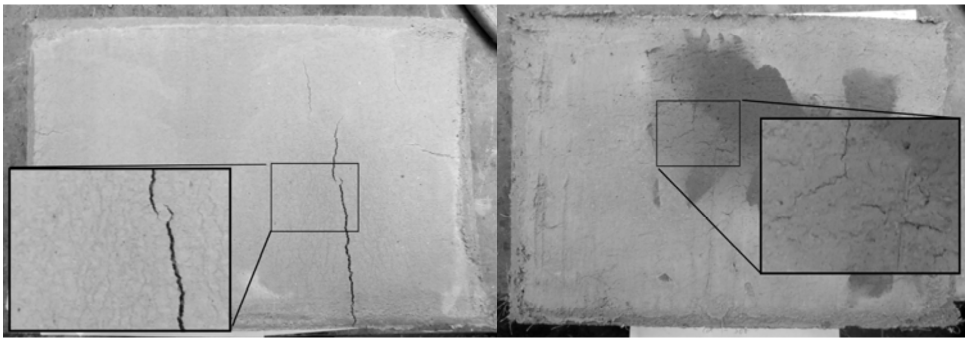

Figure 3. Mortars without fibres (EM0) (left) and mortars with polypropylene (EM4) (right).

5.4 *Water absorption by capillarity*

Figure 4 shows the obtained capillarity coefficients and the curves representing the kinetics of water absorption by capillarity. The slope of the first linear straight section of the water absorption curve corresponds to the capillarity coefficient.

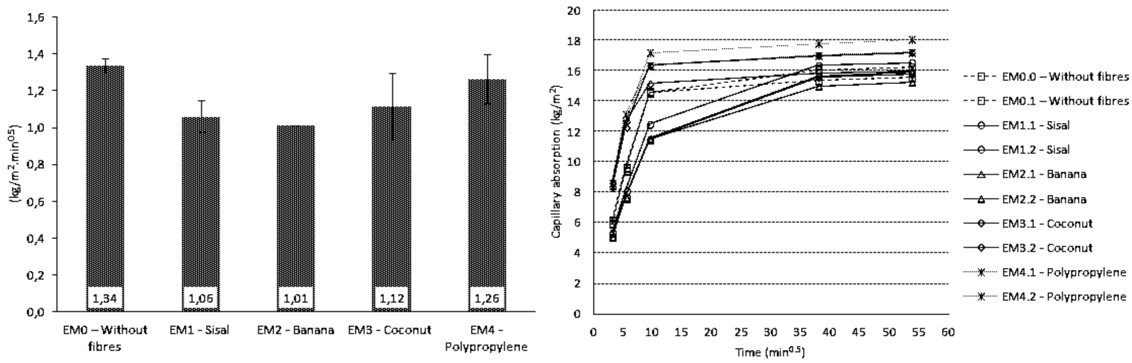

Figure 4. Capillarity coefficient and the respective curves of water absorption.

The obtained values of the capillarity coefficient reveal a slight decrease on the water absorbed in the mixtures made with fibres, mainly with natural fibres (EM1, EM2 and EM3).

Regarding the curves of water absorbed by capillarity, comparing it with the mixture without fibres (EM0), it can be observed that the mixture EM4 of polypropylene fibres absorbed more water and the mixtures EM1 and EM2 (fibres of sisal and banana) absorbed less water at the 90 minutes (≅ 10 $min^{0,5}$). However at 24 (≅ 38 $min^{0,5}$) and 48 hours (≅ 54 $min^{0,5}$) there are no significant differences among the tested mixtures.

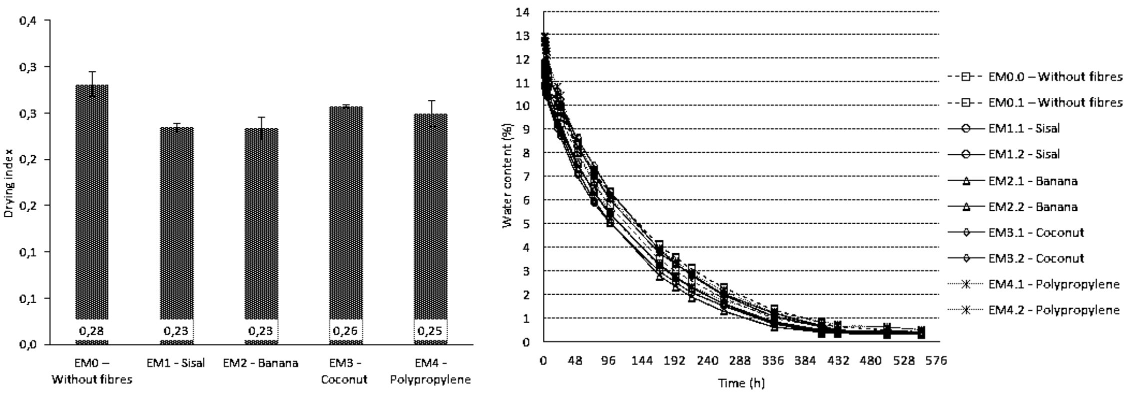

Figure 5. Drying index and curve of evaporation.

5.5 *Drying*

The behaviour of the different mixtures during the drying test is showed in Figure 5, through the drying index and curve of evaporation. This property is important for plastering mortars, once these are used in interiors, where it is expected that mortars dry faster in order not to increase the relative humidity in interior rooms.

The drying index was calculated according to the formula of Cultrone, G. et al (2007).

The results reveal that, although their similarity of magnitude, it seems that the incorporation of fibres (especially the sisal and banana fibres) contributed to a slight reduction of the time of evaporation. It was noted that the mixtures with an initial lower water content dried faster.

5.6 *Adherence to the support*

Table 7 shows the results of the pull out tests, presenting the values of tensile strength, its coefficient of variation and the prevailing typology of rupture.

It is noted a higher coefficient of variation in the standard mixture (EM0) what makes the evaluation more difficult. However, in general, the results reveal that the tensile strength values, comparing with the mixture made without fibres (EM0), the incorporation of fibres do not seem to affect significantly the adherence of mortars to the support.

Regarding the typology of rupture, it was noted that: i) the mixture without fibres (EM0) and the mixture with polypropylene fibres (EM4) had a rupture mostly adhesive (in the coating plane of the support); ii) the mixtures with banana and coconut fibres (EM2 and EM3) had a rupture mostly cohesive (within the coating plane); iii) and the mixture with sisal fibres had a mixed rupture. In general, these results show that the tensile strength of mortars should be close to the tensile of adherence between the mortars and the bricks.

Table 7. Results of pull out tests and typology of rupture.

Mixtures	Average tensile strength (MPa)	Coefficient of variation (%)	Prevailing typology of rupture
EM0 - Without fibres	0,13	20,74	Mostly A
EM1 - Sisal	0,09	9,47	Mixed AB
EM2 - Banana	0,12	9,50	Mostly B
EM3 - Coconut	0,10	5,57	Mostly B
EM4 - Polypropylene	0,10	4,83	A

A - Adhesive rupture (in the coating plane of the support); B – cohesive rupture (within the coating plane).

6 CONCLUSIONS

The incorporation of natural fibres, sustainable and inexpensive, can be a good solution to solve the general problem of earthen mortars, the cracking by shrinkage. The obtained results highlight that the cracking decrease and the properties in dry state (mechanical and water behaviour) practically have not been affected.

Concerning the mentioned requirements for plastering earthen mortars, one can conclude that these mortars in general comply with the recommended values. In flexural tensile strength, the obtained values were higher than 0,27 MPa (requirements between 0,2 and 0,7 MPa), but at compressive strength these mixtures only comply with the lower recommended values (≥0,5 MPa) for secondary spaces. However, a significant increase of resistances over time is expectable. In water absorption by capillarity, the obtained results in these mixtures complies the recommended values (between 1 and 1,5 $kg/m^2.min^{-0,5}$. In pull-out tests, most of the mixtures complies the minimum of 0,1 MPa of tensile strength recommended for earthen mortars. But, for replacement or renewal plastering the obtained values are, in general, between the suggested values (0,1 to 0,3 MPa or cohesive rupture by the plaster).

In addition, the studied mortars, also had a good behaviour concerning the drying after water absorption, revealing that these will not compromise the relative humidity in interior rooms, present a good workability and were very easy to apply in the used support (ceramic bricks).

Regarding the sustainability, comparing this type of mortar (with earth, lime and natural fibres) with conventional plastering mortars of lime, gypsum or cement, the clay content can reduce, partial or completely, the percentage of processed binder. The processed binders require a considerable energy consume in its manufacture, therefore, this reduction is a good contribute for sustainability. Comparing with simple earthen plasters, made without stabilizer, the sustainability of the manufacture is lower, but the mechanical resistance and durability could be higher. Thus, considering the long term performance, the addition of stabilizers will be beneficial.

However, the plastering mortars with earth and lime with natural fibres, being a reappearing material, deserves more research study to provide more guarantees in its application, due to the multiplicity of fibres and the variability of soils and limes used.

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Rainwater Harvesting Systems in Buildings: Rapid Changes with Substantive Improvements

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ABSTRACT: Rainwater harvesting systems in buildings have experienced a wide development in several countries, not only for reasons of rational water use, but also as a contribution to the reduction in peak flood during periods of precipitation. In Mediterranean countries the harvesting of rainwater has always been a traditional practice, with simple technological solutions. However, growing development of public water systems in the last century has resulted in a progressive abandoning of these solutions, with concomitant loss of a large part of the traditional knowledge which supported them. Scenarios of water scarcity and water stress, nevertheless, are fomenting the interest in the reinventing of these systems, based on recent, technologies, more economic and safer.This paper summarizes the main technical-scientific studies developed in recent years in Portugal by ANQIP,an NGO that works on the implementation of water-efficiency measures in buildings,aiming to improve these systems and encourage their dissemination.

1 INTRODUCTION

Rainwater harvesting systems in buildings have seen considerable development in several countries, notably in Brazil, Great Britain and Germany, to encourage the rational use of water and/or to help reduce peak flood during periods of precipitation.In Portugal, especially in the South, the harvesting of rainwater has always been a traditional practice, with simple technological solutions, but the growing development of public water systems in the last century has resulted in a progressive abandoning of these solutions, losing a large part of the traditional knowledge which supported them.

However, the scenarios of water scarcity and water stress in the Mediterranean basin are raising a growing interest for the reinventing of these systems, based on recent, more economic and safer technologies (Silva-Afonso & Pimentel-Rodrigues 2011). In fact, the harvesting of rainwater in the context of promoting the global water efficiency in buildings may play an important part in reducing this stress as well as helping to reduce flood peaks in the winter (Silva-Afonso & Pimentel-Rodrigues 2010).

But it should be noted that in comparison with other geographic regions, the Mediterranean climate is characterized by relatively long periods of drought, approximately three months, coinciding with the hot period, what means a time difference between the precipitation period and the period of greatest need of water. This leads to the need to adapt the solutions that are generalized in other countries as, for example, the retention times and the need of deviation of the first flush (Silva-Afonso 2009).

In general, the recommended period of water retention in the standards published in different countries do not go beyond the three weeks. This period is clearly reduced for applications in countries with Mediterranean climate, forcing the installations to use water from the public supply network in much of the summer.

2 THE SPECIFICITIES OF THE PORTUGUESE APPROACH

Due to the initiative of a civil society association that works on the implementation of water-efficiency measures in buildings (ANQIP - Portuguese Association for Quality and Efficiency in Building Services), Portugal was one of the first European countries to develop technical specifications and certification schemes for these systems, which are not yet covered by standards or regulations in most countries.

The use of rainwater in buildings was the object of the development of a Technical Specification from ANQIP – ETA 0701 (ANQIP 2009a). This specification has 6 chapters (Introduction, Definitions, Legal and regulatory references, General aspects and certification, Technical Provisions and Maintenance), and contains the general rules for the design and construction of these installations in Portugal.

It is important to highlight that this Specification recommends the Certification of installations, for technical quality and public health reasons, as there are still no standards or regulations applicable in Portugal. This certification implies intervention from ANQIP in the prior analysis of the project, the execution of inspection of the works, on the requirement for a maintenance plan and also in the certification of installers. The certification system was established in Technical Specification ANQIP ETA 0702 (ANQIP 2009b).

Technical Specification ANQIP 0701 used, to a large extent, the experience of other countries. However, compared to other geographical regions, the Mediterranean basin climate, covering much of Portugal, is characterized by relatively long dry periods, approximately three months, coinciding with the hot period, which leads to the need to adapt solutions to suit.

One aspect to which special attention was given was the need to divert the first flush, since the prolonged dry periods can aggravate the problem of pollution of these first waters. Pertaining to the sizing of the tank, and due to the long dry and hot periods which characterize the Mediterranean climate, it is generally important to prolong the storage period, in particular when rainwater is used for watering gardens.

To establish the maximum storage period allowed, ANQIP developed a water quality control monitoring system at a pilot facility (Lança & Silva-Afonso 2011) analyzing, over several weeks, the essential chemical, physical and micro-biological parameters (including *Legionella*) in the tank and in the uses (sprinklers for watering gardens). As a result of this study, ANQIP established, in ETA 0701 a maximum storage period of up to three months, significantly higher than that set in other foreign standards, but which was found to be feasible in the context of the Mediterranean climate and may contribute to the increase in rainwater harvesting facilities.

The runoff coefficients in the Mediterranean climate can also be strongly influenced by the absence of precipitation in prior periods, and this issue was also studied in the preparation of the ETA 0701.The knowledge of the diagrams of water use, defining the consumption peaks and influencing the sizing of the networks, is another of the current research topics by the ANQIP.

3 ANALYSIS OF THE EVOLUTION OF WATER QUALITY WITH PROLONGED RETENTION. A CASE STUDY

The ANQIP developed a study to evaluate rainwater quality and safety on a groundwater storage tank of an elementary installation used for garden watering, with a sprinkler irrigation system, with a prolonged retention. The facility used in the study is located in the regional headquarters of the Portuguese Order of Engineers, in Coimbra (Figure 1).

In this office there are two buildings: a secular building almost recovered, and another recently opened building with contemporary architecture. During the reconstruction / construction it was decided to implement a simple system of collecting rainwater, according to more traditional and simple procedure for storage tank.

The rainwater is collected from the roof surfaces, with an elementary parapet gutter system, connected to the storage tank with simple stacks. At the cement storage tank, with the maximum capacity of 50 m^3, under the floor, with no light, the water stays as long as possible, depending of the consumption in the garden watering, without any treatment (Figure 2).

The major purpose of monitoring control was the evaluation of water quality during the summer, analyzing essential chemical, physical and microbiological parameters. Sampling was conducted in two parts of the system, particularly in the storage tank and sprinklers, since they are the most critical locations in the facility.

Figure 1. The sprinkler system

Figure 2. The water storage tank under the floor terrace

Whereas the storage of water will be made for a period far exceeding 30 days, it is essential ensure a quality control. The implementation of the building in an urban area is a risk factor due to the proximity of wooded areas and a green spot, with significant pollen and particles deposition, and the permanence of birds.

An analytical plan was established with two batteries of tests with ranges of parameters and different frequencies:

Level 1 – Monthly complete analysis (physic-chemical and microbiological), allowing an assessment not only of the characteristics of rainwater but also those arising from precipitation over the coverage areas with eventual contamination, and from the collection (Table 1),

Level 2 - Weeklyanalysis of the main physic-chemical and microbiological contaminants control, to allow the characterization of the profile quality changes, as a function of storage time. (Table 1)

Level 3 - If the results determine an eventual need of disinfection procedures, or water treatment, this level will introduce the methodology for monitoring and control to define.

The parameters were chosenaccording to the applicable legalvalues for irrigation water and surface water,considering the specified in the Portuguese Decree-Law No. 236/96, with respect to the Maximum Recommended Values for water for irrigation, (MRV_1), and Maximum Recommended Values for water for human consumption (MRV_2).

Should be noted that exists different standards and guidelines in several countries, particularly USA, Australia, Germany, Canada and Brazil, for the use of rainwater. The criteria for using water-based microbiological monitoring are variable, as can be seen inTable 2.For the monthly and weekly monitoring are presented in Tables 3 and 4 some results obtained in the first year of monitoring (2010).

Table 1. Level 1 and level 2 - Parameters and control plan

<table>
<tr><th>Parameters</th><th>Units</th><th colspan="2">Frequency</th></tr>
<tr><td>Temperature</td><td>ºC</td><td rowspan="23">First characterization analysis and then monthly</td><td rowspan="6">Weekly or if justifiable</td></tr>
<tr><td>pH</td><td>-</td></tr>
<tr><td>Color</td><td>Hz</td></tr>
<tr><td>Turbidity</td><td>NTU</td></tr>
<tr><td>Conductivity</td><td>µS/cm</td></tr>
<tr><td>Dissolved oxygen</td><td>mg/l</td></tr>
<tr><td>COD</td><td>mg/l</td><td rowspan="8"></td></tr>
<tr><td>BOD</td><td>mg/l</td></tr>
<tr><td>Hardness</td><td>mg/l</td></tr>
<tr><td>Chlorides</td><td>mg/l</td></tr>
<tr><td>Ammonium</td><td>mg/l</td></tr>
<tr><td>Nitrites</td><td>mg/l</td></tr>
<tr><td>Nitrates</td><td>mg/l</td></tr>
<tr><td>Sulphate</td><td>mg/l</td></tr>
<tr><td>Suspended solids</td><td>mg/l</td><td rowspan="2">Weekly or if justifiable</td></tr>
<tr><td>Total solids</td><td>mg/l</td></tr>
<tr><td>Zinc</td><td>mg/l</td><td rowspan="4"></td></tr>
<tr><td>Iron</td><td>mg/l</td></tr>
<tr><td>Chromium</td><td>mg/l</td></tr>
<tr><td>Lead</td><td>mg/l</td></tr>
<tr><td>Total coliforms</td><td>NMP/100ml</td><td rowspan="2">Weekly or if justifiable</td></tr>
<tr><td>Heat-resistant coliforms</td><td>NMP/100ml</td></tr>
<tr><td>Legionella pneumophila</td><td>NMP/100ml</td><td></td></tr>
</table>

Table 2. International Comparative Values

Parameters	NBR 15.527/07 Brazil	EPA	Australia	Canada
Total coliforms (NMP/100ml)	Absence	Absence	-	-
Heat-resistant coliforms (NMP/100ml)	Absence	Absence	< 150	<150
Turbidity (NTU)	< 2.0 or < 5.0 for less restrictive uses	< or = 2	-	50
Color (Hz)	< 15 µH	-	-	-
pH	6.0 - 8.0	6 - 9	6.5 – 8.5	6.5 – 8.5

As it can be compared, all the analytical values are below the indicated limits, according to the global characterization of rainwater. Considering the absence of any filtration or disinfection system is relevant the quality confirmed. Note that being a new tank of cement, without any special cleaning or disinfecting, that can justified some uncharacteristic values of water, resulting from the materials, but without any expression or significance. This was one of the studies which led to allow water storage periods up to 90 days in the ETA 0701, in installations with reservoirs built properly, ensuring the protection of the water from temperature and light.

Table 3. Level 1 – Monthly sample analytical results

	ANALYSIS 1					
	June, 6		September, 8			
PARAMETER/ /UNITY	Tank	Sprinkler	Tank	Sprinkler	MRV_1	MRV_2
Total Coliforms (UFC/100ml)	1	0	0	Insufficient water for operation of the sprinklers		50
Fecal Coliforms (UFC/100ml)	0	0	0		100	20
Temperature (°C)	23.5	22.8	23.1			22
Turbidity (NTU)	2,77	1,20	4			
pH (E. Sorensen)	7.57	7.81	7.92		6.5–8.4	6.5–8.5
Conductivity (µS/cm)	130	135	153			3
Color (mg PtCo/L)	<5	<5	<5			10
Dissolved oxygen (%)	75.1	99.2	84.9			70
Chemical Oxygen Demand COD (mg O_2/L)	<10	<10	<10			-
Biochemical Oxygen Demand – BOD (mg O_2/L)	<3	<3	<3			3
Total Hardness (mg $CaCO_3$/L)	35.0	37.0	34.5			
Ammonium (mg NH_4/L)	<0.050	<0.050	<0.050			0.05
Nitrate (mg NO_3/L)	2.2	1.2	1.8		50	25
Chloride (mg CL^-/L)	9.7	<4	<4		70	200
Nitrite (mg NO_2/L)	<0.020	<0.020	<0.020			
Sulfate (mg SO_4/L)	8.7	6.2	6.7		575	150
Total Suspended Solids (mg/L)	<3	<3	<3		60	25
Total Solids (mg/L)	74	75	94			
Zinc (µg Zn/L)	$1.6x10^2$	<10	<10		2	0.5
Iron (µg Fe/L)	$4.6x10^2$	27	<10			
Cadmium (µg Cd/L)	<1.0	<1.0	<1.0		0.01	0.001
Lead(µg Pb/L)	<5	<5	<5		5	-
Legionella Pneumophila (UFC/100ml)	Not detected	Not detected	Not detected			

4 INFLUENCE OF PROLONGED PERIODS OF DROUGHT IN THE DEFINITION OF THE RUNOFF COEFFICIENTS

In general, the value 0.8 is adopted for the runoff coefficient (C) in most existing standards. However, the value of C varies significantly with the height of the precipitation and in the case of green roofs with precipitation in previous periods.

This aspect becomes relevant in Mediterranean climates, due to the existence of periods of intense rainfall and prolonged drought periods. Thus, when the sizing of the tank is made based on the monthly average precipitations, the ANQIP recommends, based on studies carried out, that should be adopted the values of C shown in Table 5, being C_M the runoff coefficient to the month M, P_M the rainfall in this month (in mm) and P_{M-1} the rainfall in the previous month (also in mm).

Table 4. Level 2 – weekly sample analytical results

	ANALYSIS 2									
	July, 14		July, 20		July, 28		August, 4		September, 21	
PARAMETER (Unity)	Tank	Sprink.	Tank	Sprink.	Tank	Sprink	Tank	Sprink	Tank	Sprink.
Total Coliforms (UFC/100ml)	1	0	0	0	0	0	0	0	10	Insufficient water for operation of the sprinklers
Fecal Coliforms (UFC/100ml)	0	0	0	0	0	0	0	0	0	
Temperature(°C)	23,8	22,2	22,8	23,4	24,4	24,4	23,7	23,7	25,7	
Turbidity(NTU)	0,74	0,55	1,95	1,65	1,98	1,98	12,5	3,72	1,22	
pH(E. Sorensen)	8,16	8,55	8,73	8,66	8,64	8,64	7,85	7,8	8,03	
Conductivity(µ S/cm)	140	139	139	139	140	140	139	146	163	
Color (mg PtCo/L)	<5	<5	<5	<5	-	-	5	<5	<5	
Dissolvedoxygen (%)	75,9	78,2	59	75,2	-	-	-	-	77,7	
Total Suspended Solids(mg/L)	<3	<3	<10	<10	-	-	-	-	<3	
Total Solids(mg/L)	68	69	90	87	-	-	87	100	114,5	

Table 5. Recommended values for the runoff coefficient (*C*)

Roof type	Value of *C* to consider when the sizing of the tank is made based on the average monthly precipitations	Average value of *C* to be considered for annual rainfall
Impervious roofing (tiles, concrete, etc.).	$C_M = 0.06\ P_M^{0.60}$, with a maximum of 0.95	0.80
Extensive green roofs without watering * (and thickness *e*> 150 mm)	$C_M = 0.06\ (P_M - R)^{0.60}$, with a maximum of 0.55, being $R = 0.25.e - P_{M\text{-}1}$, with a minimum of 0	0.30
Intensive green roofs without watering * (thickness $e \leq 150$ mm)	$C_M = 0.06\ (P_M - R)^{0.60}$, with a maximum of 0.70, being $R = 0.25.e - P_{M\text{-}1}$, with a minimum of 0	0.50

* In the case of watering, the respective value must be added to the precipitation P_M and / or $P_{M\text{-}1}$, as appropriate.

5 CONSUMPTION PROFILES IN DWELLINGS WITH RAINWATER HARVESTING. A CASE STUDY

For a better knowledge of the consumption profiles of rainwater and of water from public network in residences, the ANQIP installed data-loggers in a Portuguese demonstration sustainable house (a villa of medium size), making records on an hourly basis every day. The villa has four residents, but they are not at home all day, and so it was considered in the calculations an occupation weighted of 2.5.

In this house, rainwater is used in flushing cisterns, in washing machines, in outside washes and in watering the garden (in the yard there is a small garden for vegetables).As examples of the profiles obtained, are shown in Figures 3, 4 and 5 the diagrams recorded on May 7, 2013.

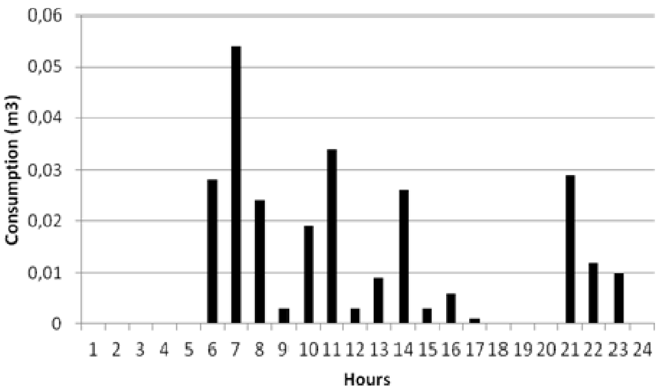

Figure 3. Consumption of rainwater on May 7, 2013

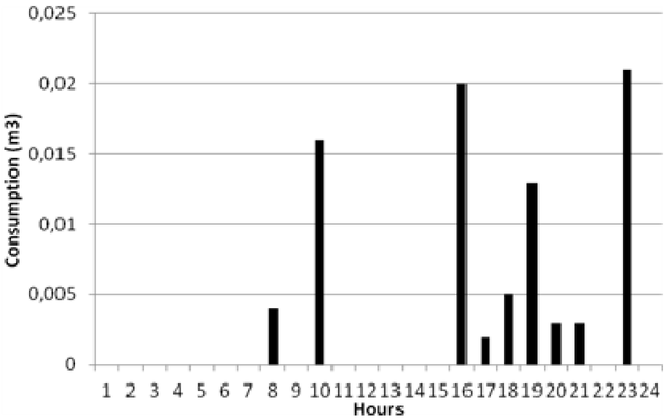

Figure 4. Consumption of water from the public network on May 7, 2013

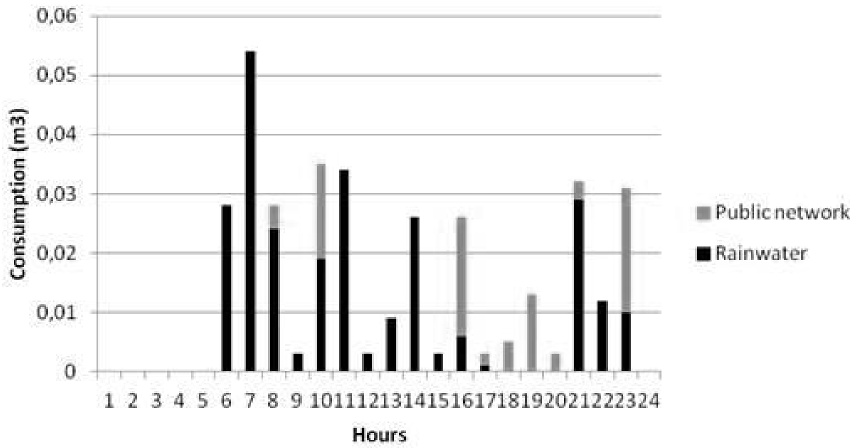

Figure 5. Consumption of rainwater and water from the public network on May 7, 2013

This study is still ongoing, but there are already some indicators regarding capitations and peak factors, which are summarized in Table 6. The capitation seem high, especially with regard to rainwater, but it is important to remember that during much of the period of record did not rain, forcing to watering the garden.

The next phases of the study will include the setting of parameters for an optimum sizing of the building supply networks, as well as research about the correlations that can justify the various values obtained during the day.

Table 6. Capitation values and peak factors during the first month of registration

Water source	Average monthly consumption (m^3)	Average daily consumption per inhabitant (L/inhab.*day))	Daily peak	Hourly peak
Rainwater	8.50 (76.6%)	113.0	5.9	16.1
Water from the public network	2.60 (23.4%)	35.0	2.1	7.8
Rainwater + water from the public network	11.1	148.0	4.6	15.5

6 CONCLUSIONS

The efficient use of water is an environmental must for every country in the world. Some countries, like Mediterranean countries, must develop measures to ensure this as a matter of urgency, since water availability could be significantly affected in the short- medium-term.

The use of rainwater is one of the solutions that are beginning to generalize in many countries for reasons of sustainability. Even though the Mediterranean climate is not really suitable for proper rainwater harvesting this should still be considered as a measure viable to increase the water efficiency in buildings.However, the differences in climate recommend an adaptation of the solutions already adopted in other countries, requiring different technical specifications in the design of systems, supported by local research.

That's why ANQIP, a Portuguese association of civil society working in the field of water efficiency in buildings, decided to promote diverse research and the development of technical specifications for the rainwater harvesting in buildings, allowing rapid and significant improvements in the design of these systems in Portugal and stimulating its increasing use.

The studies developed by ANQIP aim to adapt and improve the design of these installations for the Portuguese conditions, with Mediterranean climate, examining the possibility of extending the periods of storage without risk to public health, studying the most appropriate runoff coefficients for the design, especially when using green roofs, and analyzing the diagrams of consumption, in order to provide basic data for correct sizing of the networks, when the supply of the building is shared with the public network. In fact, ANQIP seeks to update and improve traditional practices in Portugal, which were appropriate to the low capitations of the past,where the public health risks were not always safeguarded. Further research or the continuation of ongoing research is required to clarify some aspects as, for example, the determination of the coefficients of runoff in green roofs for specific local climates.

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The energy of water: An evaluation of direct electricity savings due tostrategies of water preservation in a social housing compound

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ABSTRACT: The benefits associated with the safeguard of the hydric resource not only can contribute to face local water scarcity problems. The use of high quality water in the built environment also has significant impacts on energy consumption and CO_2 emissions. The supply of drinking water includes extraction, treatment and distribution through a network under pressure. The amount of energy that these processes require changes depending on a number of factors and the average value calculated by the European Environment Agency is 0.64 kWh per cubic meter of water used by the final user. A case study is presented, concerning the refurbishment of a social housing estate built in the early 80s near Venice. Different strategies focusing on a more rational use of water are discussed, enhancing benefith both for hidric and energy consumption.

1 INTRODUCTION

All processes to supply water to building as well as wastewater treatments, are complex practices, which can generate pollutants, greenhouse gases and can be highly energy-intensive. A large amount of scientific studies are being published to drive the choice among different configurations of water network using different tools assessingenvironmental impacts. The most commonly considered impacts of water cycle on the environment include resource depletion such as non-renewable energy consumption, GHG emissions, human health and ecosystem quality (Vince et al. 2008).

At the building scale it may be relevant the development of tools gathering all the strategies focused on the more rational use of the hydric resource, in order to compare their effectiveness on the basisof objective data, thus helpingdecision makersto take more conscious and effective decisions.Thispaperaims at contributing to that, analizingthe direct energy consumptionofwater suppliedto residential buildings by water autorities. It does not consider energy used by householde.g. for heating, for cooking or for powering additional pumps.

The first partof the study collects and analyzes thestrategiesfor the protectionof water resourcesapplied to buildings, whilethe second partverifiesthe applicationof these strategiesto aspecificcasestudy, a social housingcompound built nearVenicein the 80s. The final sectioncalculatesthe direct energyconsumption saved by the application of these strategies inthe case studyandin other possible scenarios.

2 WATER AND ENERGY CONSUMPTION

In October 2010, the United Nations Congress stated that the right to water is an integral part of the existing agreements on human rights, and that States have the responsibility to ensure the realization of this basic human right. Accordingly, many national institutions are developing rulesand guidelines focused on the preservation and valorisation of water resources. A study over national and regional Italian regulation and procedures focused on the preservation of water in the built environment have been developed by the author within the framework of the Italian research program PRIN 2008, «Renovation, regeneration and valorization of social housing settlements built in the suburban areas in the second half of last century», under publication.

In Italy, within the 5.31 billion of cubic meters of potable water billed in 2008, 82.1% was for civil use, 16.5% for industrial use and 1.4% for agriculture (ISTAT 2012). In general, in developed countries buildingsare responsible for the consumption of a large amount of fresh water.The International Council for Research and Innovation in Building and Construction (CIB) inserted water among the topics discussed in its international conferences. Since Agenda 21 on Sustainable Constructions (CIB, 1999) it highlighted the problems of the lack of fresh water, of leakage from distribution systems, inefficient water use, urban waste pollution and urban runoff.

The benefits associated with the preservation of water are relevant, including the safeguard of water resources quality, the reduction of the load on existing supplies and the reduction of energy consumption and CO2 emissions (EPA 2012). As a matter of fact, drinking water supply includes extraction, treatment and distribution through a network under pressure for user consumption. The amount of energy required by these processes depends on a number of factors, including the difference in altitude and the distance between source and final user and the quality of raw water. The European average value calculated by the European Environment Agency is 0.64 kWh per cubic meter of water consumed by the final user (EEA 2012). A research over water-energy nexus in Spain calculated that total water withdrawal (including agricultural and industrial uses) was 35 billion of cubic meters per year and the total water-related energy consumption was 16.5GWh, accounting for some 5.8% of total Spain electricity use (Hardyet al. 2012).

2.1 *Strategies to save energy through safeguarding water*

Sustainability indicators enhancethe theme of water conservation and comparative studies discuss the strategies proposed in each indicator highlightingdifferences among tools (Ilha et al. 2006).

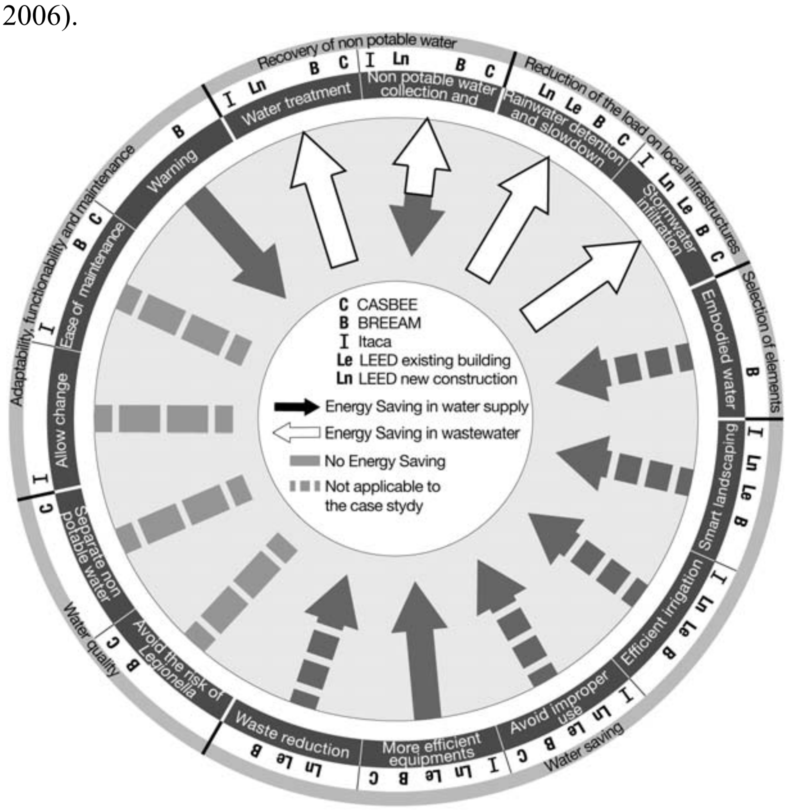

Figure 1. Water safeguard strategies. Each strategy has been analysed underlying if it can generate direct energy saving for water input, for wastewater output or if cannot generate direct energy saving.

Five sustainability indicatorswere examined: LEED for New Construction and Major Renovations, 2009; LEED for Existing Buildings Operations and Maintenance, 2009; CASBEE for New Construction, 2010; Protocollo Itaca Nazionale 2011 residenziale; BREEAM Multi Residential 2008. The comparison has enhanced 6 different requirements and 15 strategies to satisfythe requirements. A complete description of requirements and possible actions/technologies to fulfil them has been published in the proceeding of the final conference of Cost Action TU0701 (Girardi2012).

3 APPLICATION TO A CASE STUDYIN MARGHERA

3.1 *Description*

The complex of via Bosco in Marghera (Venice), is a social housing estate built in 1981. The compound includes 167 apartments divided into three different typologies, incorporating duplex apartments. Two 8 floors buildings are connected with two smaller constructions about 8 metres high. The ground floor is occupied by garages, depositories and technical rooms, including the ones containing the booster pumps to rise water. The area includes a huge garden (13600 m^2) and parking and paths (8000 m^2). The rooftopareais about 940 m^2 for each of the main buildings and about 390 m^2 for each of the connection buildings.The construction was built with concrete structure and precast concrete panels, with cavity and internal wall in solid bricks. All systems including water supply and sewage network are contained in empty columns.

Data on water consumption of the complex has been produced by the network authority namely Veritas. The consumption per different uses can be summarized in the following Table 1. Percentages are based on Veneto Regional Agency for prevention and protection of the Environment (ARPAV 2005), and on a study committed by the European Commission on water performance in buildings (Bio Intelligence Service, 2012). Average data are also provided.

Figure 2. The social housing compound in via Bosco, Marghera (Venice)

Table 1. Household water use

Action	EUREAU		ARPAV		Average	
	%	m^3/year	%	m^3/year	%	m^3/year
Bathing/showering	35	6174	39	6880	37	6527
Toilet flushing	25	4410	20	3528	22.5	3969
Washing clothes	14	2470	12	2117	13	2293
Dish washing	8	1411	10	1764	9	1588
Cleaning and irrigation	5	882	6	1058	5.5	970
Drinking and cooking	5	882	7	1235	6	1058
Other	8	1411	6	1058	7	1235
Total	100	17641	100	17641	100	17641

Strategy 1: Recovery of non potable water

The actions to recover non-potable watersare differentdepending onthe kind ofwater needing the treatment. Sewagerequiresbiological or chemicaltreatmentsbefore reuseor dispersion.However, the on-site treatment of foul wateris most of the times utilized for new construction in isolated sites, barely applied to existing buildings in urban areas, as they are supposed to be already connected to the sewage network.

Rainwater is good quality raw water, except for the rain falling in the first 15 minutes (according to the Italian regional lawLombardian°62, 1985), which collects pollutants from the atmosphere and from the soil and should be discharged. Rainwater can be collected in tanks of different materials (usually polyethylene) and supplied for appropriate uses, mainly for toilet flushing and cleaning. The system usually includes a filter to discard the first rainwater, a centrifugal pump and an overflow system to get rid of the excess of rain. There are different norms to calculate the size of the components of a rainwater harvesting system, including UNI/TS 11445:2012: I*nstallation for use and collection of rainwater not intended for human consumption, Design installation and maintenance* and DIN 1989-1:2001-10: *Rainwater harvesting systems*. According to the last one, the harvesting theoretical capacity E_r depends on the collecting area A_A (2970 m^2 including rooftops and elevated walks), on the yield coefficient e (0.8 for flat roofs without gravel), on the annual rainfall h_N(748.4 l/m^2) and on the Hydraulic efficiency coefficient η (0.9 filter maintained on a regular basis):

$E_r = A_A e\, h_N \eta = 1600 m^3/year$

It should be noted, however, that according to Table 1, the need of water for toilet flushing is about 3400 m^3/year, which is largely higher than the rainwater harvesting theoretical capacity. The result is in keep with existing literature showing that rainwater harvesting systemsin similar rainfall conditions are adequate to fulfill reclaimed water needs in single houses, while are less adequate for multi family buildings needs (De Gouvello et al.2004).

Greywaterreuse offers the opportunity of a more significant amount of water as well as a source not dependent on the seasonal variability of the weather. In addition, the availability of greywater and the demand of reclaimed water for appropriate uses generally corresponds. However, reuse of greywater is more complex, especially in multifamily buildings where its use without purification should be avoided (Working Group on Domestic Reclaimed Water 2010).

Some researches do not include wastewater from kitchen in the reclaimed water sources. In fact it can be contaminated with pollutants whose treatment can be more difficult. Some interesting studies examine the possibility to reuse grey water after applying phytodepuration. Gomez et al. 2012 proposes a system to treat grey water from showers, bidets and washbasinsdirectly in a green rooftop.The systems consists on some primary tanks receiving grey water from which water is pumped every 24 hours to a centralized tank and from this to the artificial wetland. After 7 days of staying the water is moved to another tank and then supplied for compatible uses through a dual network. The novelty of the system relies on an innovative industrialized phytodepuration module reducing the area needed for depuration to 12 m^2 per cubic meter of water (instead of almost 20m^2).

A similar configuration could be easily applied to via Bosco compound. Tanks could be installed in 4 depositoriesin the ground floor which at present are unused, while the phytodepurationmodules could be located in the rooftops of the two storeys constructions connecting the main buildings. According to Table 1, Bathing/showering consumption is 18m^3/day on average and, even calculating a loss due to evaporation of 30%, could be largely sufficient to fulfill the need for toilet flushing.

With such a configuration, possible benefits includes the reduction in average of 22.5% of the volume of drinkable water used for inappropriate practices, the decrease of the urban wastewater volume to be treated, the increase of thermal inertia of the rooftops and eventually new green spaces for users.

Strategy 2: Water saving
The optimization of water use is one of the basic actions aiming at the safeguard of hydric resource.A research commissioned by EU defined three different strategies to fulfil the goal, namely Horizontal policies (metering, cost strategies and awareness rising), Product-level policies (labelling and minimum water efficiency requirements for products) and Building-level policies (water performance rating, minimum water efficiency requirements for buildings and certification scheme for water reuse) (Bio Intelligence Service, 2012).

Anyway, in the actual refurbishment of a building we should focus on substituting traditionalWuPs (Water-using Products) with more efficient ones.Actions to reduce the consumption in buildings include the use of automatic control systems, automatic shut-off devices, systems for the return of the hot water, dual flush toilets and low flow fixtures and appliances.The results for possible water savings are summarized in Table 2.

Table 2. Household water saving

Actions	Water use		Product water saving			
	%	m^3/year	Description	Performance	Saving (%)	Saving in the case study (m^3/year)
Bathing/showering	37	6527	water-saving showerhead	3-4.5 l/flush	8	1411
Toilet flushing	22.5	3969	low flush toilet	6-7 l/minute	22	3881
Washing clothes	13	2293	AAA rated washing machine	40% less water	0.2	35
Dish washing	9	1588	AAA rated dishwater	20% less water	0.9	159
Cleaning/irrigation	5.5	970	-	-	-	-
Drinking and cooking	6	1058	-	-	-	-
Other	7	1235	-	-	-	-
Total	100	17641	-	-	31.1	5486

Strategy 3: Warning
This strategyincludes all actions and technologies to detect leakages and malfunctioning in water system inside the buildings. Although major losses are in water distribution networks, the implementation of smart water meters, which collect real time water use information, can be a useful technology to improve water efficiency in buildings. There are products on the market that are designed to detect leaking and inform users by an alarm as well as suspend water supply.Some devices also are able to switch off the water when the building is unoccupied.

The amount of water loss by leakage depends on many specific factors such as the obsolescence of the network and of WUPs. United States Environmental Protection Agency (EPA) calculates that a percentage of about 5 percent of American households suffer from water leakage causing the lost of an average of about 300 liters a day.

3.2 *Direct energy saving*

The direct energy consumption to supply buildings with potable waterlargely dependson water qualityat the sourceand on the total manometric height between the water resource and the consumers.In Italy, 35.7% of raw water is extracted from good quality superficial springs, 49.8% from wells and only 0.1% from brackish or salt water (ISTAT 2012).

Water networks in the central-south part of the Veneto Region, including the case study area,have been gathering together in the Aqueduct Scheme of Central Veneto (SAVEC). In SAVEC, raw water mainly originates from the big mountain range namely Dolomites and its water quality is good at average value. InOverall, the network is designed to interconnect different areas. In order to overcome seasonal lack of freshwater from a single source the network relies on multiple pumping stations from different sources. Even more, with the approval of the MO.S.A.V, the network scheme isexpected to change froma treemodel to reticular scheme. That's why to calculate the direct energy consumption of potable water supply is more appropriate to rely on average data from different sources, rather than on data from the nearest source.

Data from 9 pumping stations shows a minimum electricity consumption of 0.47 kWh/m^3 and a maximum of 0.74 kWh/m^3 (average 0.55 kWh/m^3), as in Table 3.The energy consumptionrefersto electicityusedboth forlifting and forthepurification processes.

Table 3.Direct energy for water production in some stations of SAVEC

Station	Source	Consumption kWh/m^3
BadiaPolesine	Superficial water and well	0.47
BoaraPolesine	Superficial water and well	0.5
Ponte Molo	Superficial water	0.52
Corbola	Superficial water	0.59
CastelnovoBariano	Well	0.6
Cavarzare	Superficial water	0.6
Canalnovo	Superficial water	0.61
Occhiobello	Well	0.65
Polesella	Well	0.74
Average	Various	0.55

The following Table 4 summarizes the results of the research. An evaluation of direct electricity savings due to strategies of water preservation in the case study is calculated.In addition to the minimum, maximum and average valueof direct energy consumption from pumping station of SAVEC, some data from existing literature have been compared. They refer to dissimilarities in energy consumption using different sources and extraction technologies, namely desalination of seawater with reverse osmosis, brackish water desalination, and reuse (Vince et al. 2008). Figure 3 aims at making it evident the advantages of adopting those strategies.

Table 4.Direct energy for water production in some stations of SAVEC

Water sources		Processes electricity	Yearly use of water	Yearly use of electricity	Energy saving due to water preservation strategies					
					Recovery		Saving		Warning	
		KWh/m^3	m^3	KWh/y	%	KWh/y	%	KWh/y	%	KWh/y
	Min	0,47		8291		1866		2579		332
SAVEC	Average	0,55		9703		2183		3017		388
	Max	0,74	17641	13054	22,5	2937	31	4060	4	522
BW Desalination		1,15		20287		4565		6309		811
SW Desalination		4		70564		15877		21945		2823

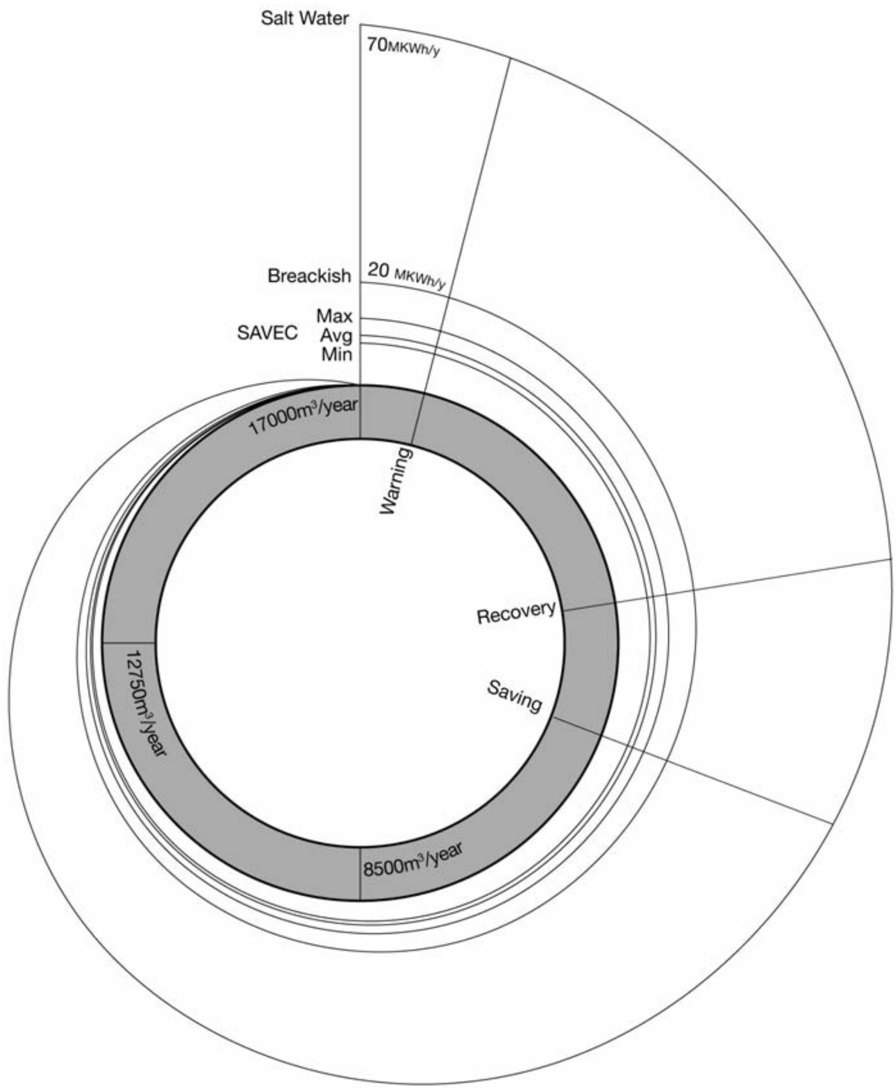

Figure 3. Direct energy saving of water safeguard strategies. In the vertical line it is arranged the energy consumption of different processes to treat the water needed by the social housing compound in a year. The radius within the grey annulus indicates water consumption.

4 CONCLUSIONS

Strategies aiming at a more rational use of water in buildings provide significant reductions in energy consumption to extract, purify and supply water by water authorities. The case study presented is set in an area where water supply is not particularly energy intensive, but in different regions the benefits in terms of energy savings can be extremely more considerable.

Further advances in this line of research should include the consideration that each water safeguard strategy need energy to be produced, supplied and disposed.Thus,crossinginput-output databased on LCA procedurewill be an appropriate methodology to improve the analysis. In addition, energy use in wastewater treatments and in chemical production of additive required to potable water production should be considered.

The expected result is the development of a tool for decision makers enabling them to propose strategies, norm and rules based on robust scientific evidences. At present, actions aiming at a more rationale use of water in buildings are mainly proposed or mandated on the base of the general consideration that water is a valuable resource. To make these arguments more robust, the theme should be considered in a more holistic way enhancing all benefits, including the ones pertinent to other fields, most importantly the water-energy nexus.

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Comparison of costs of brick construction and concrete structure based on functional units

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ABSTRACT: In the context of economic sustainability of building construction,it is an issue to decidewhich constructive solution is more reasonable withoutloosing quality. This study is about the comparison of the costs of construction ofstructural walls;conventional reticulated reinforced concrete structure filled with ceramic blocks versusunreinforced masonry with ceramic blocks. Functional units are defined as inner and outer walls to enable a further specification of the costs in order to perform a more detailed comparison without having designed a specific architecture. The results show a lower cost of unreinforced masonry construction, especially in the case of small buildings, whether for home or public services.

1 INTRODUCTION

To decide which constructive solution for a structure is more economical, regardless of the architectural form, requires information and indicators that help to find economically sustainable solutions. An instrument recommended by ISO 14040, that regulates internationally the environmental assessment and life cycle of products, is the comparison of functional units. The standard requires that for the functional units must be created equal conditions in relation to all aspects of concern that may have an impact on the scientific comparison.

For this specific case, comparing conventional reticulated reinforced concrete structureandunreinforced brickwalls both with ceramic blocks, this means that the units must have the same function regarding stability, thermal and acoustic behavior.

To compare the two constructive solutions, exterior and interior walls aredefined as functional units, with spans of 4, 6 and 7 meters and a ceiling height of 2.7 meters. The comparison is carried out between the functional units of the same span.

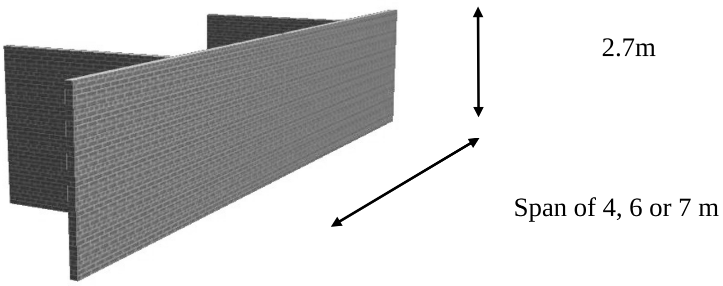

Figure 1. Brick wall as functional unity

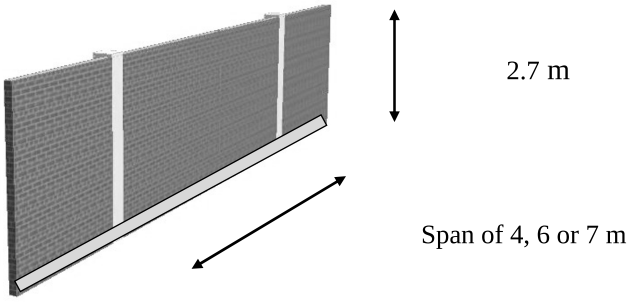

Figure 2. Wall of conventional reticulated reinforced concrete building filled with ceramic blocks as functional unit

2 CONDITIONS

The functional unit in conventional construction (CC) consists of side pillars and brick walls in between. The pillars are counted as half,as the pillar also serves for the wall that continues. The beams are considered in regard of the span. Therefore, the beam has a height of 40 cm, 60 cm and 70 cm depending on the span range of 4 m, 6 m and 7 m. As the slab is considered equal in both solutions, in case of CC the slab height of 20 cm is reduced from the beams for the quantification of the materials. For each level is just considered the lower beam as the upper beam serves for the upper level. In case of the masonry solution (M) the functional units consist simply of brickwork without columns and beams with equal dimensions of the CC solution.

The functional units are treated uncoated considering that in both solutions the coating will be the same to safeguard the same quality, concluding that the price of the structure is of interest. For thesame reason the slabs are also equal for both constructive solutions. To avoid lost of quality on the thermal and acoustical behavior, the masonry units are considered without reinforcement. According to the National Laboratory of Civil Engineering of Portugal, for safety reasons and the weak seismic behavior of masonry,it is advised not to construct masonry buildings more than 3 or 4 floors. Suitably this comparison is limited to all the aforementioned conditions.

Regarding the thermal behavior, a simplified model of calculation is used to compare the medium heat transfer coefficient in connection with the surface area of the functional units. In both construction cases, CC and M, the walls are considered with 3 layers,from the inner to the outer side a 29 cm thermal brick, 1 cm of air and 3 cm of insulation with a thermal conductivity of 0.033 W/mK. In case of CC, the surface is divided in brick and concrete zone, whereby the concrete zone, 30 cm pillars, has no layer of air. So both walls are geometrically equal and have a thickness of 33 cm without coating. For the CC unite the medium value of the heat transfer coefficient must be considered, contrary to the M unite where the surface is equaland the coefficient can be determined directly. The comparison of the heat transfer coefficients shows that in case of CC the value is 0.456 W/m^{2}K and in case of M 0.422 W/m^{2}K. As the difference is very small, it can be concluded that both cases are very similar; as equality is technically impossible adequate heat insulation is used.

Two different scenarios are considered. In the first scenario the functional units are considered for the construction of a building with 3 or 4 floors and in the second setting the building has only one or two floors. It is noted that for both scenarios the beams have the same dimensions, since the design is independent of the height of the building. The beams are designed with an overload of 5 kN/m^2, whichpermits the use of the building for public services.

In the first scenario the choice of the materials is guided by a study on the comparison of the conventional structures and unreinforced masonry (Sazedj, 2012). According to this study, to satisfy Eurocode 6, thermal bricks are used with a width of 29 cm for the outer walls and a resistant clinker brick,11 cm wide,for the inner walls. This configuration ensures the static and dynamic stability, while satisfying the needs of the thermal and acoustic comfort, compatible with a reticulated structure of reinforced concrete. The exterior walls of the conventional construction have 29 cm width using the same thermal bricks equal to the masonry structure guaranteeing the same thermal quality. Therefore the pillars with 30 cm width are well designed for constructive reasons. As, previously mentioned,the comparison concerns a construction with a maximum of 4 levels, the design of the pillars with 30 cm meets also the required resistance and there is no need to consider a larger section for the lower floors. The functional units of the interior walls in case of conventional construction consist of lateral pillars, 30 cm width as mentioned, and a normal brick of 11 cm width.

In the second scenario in case of masonry the above mentioned structural requirements in relation to the inner walls do not exist, since the height is limited to two floors, interior walls can be built with sufficient stiffness using the common ceramic bricks used in the conventional construction. Table 1 lists the materials used in the functional units in both scenarios.

Table 1. Used construction material

Material	Dimensions (mm)	Density (kg/m^3)
Normal brick	290x106x189	700
Clinker brick	237x115x70	1300
Thermal brick	294x289x189	1300

3 COMPARISON OF THE RESULTS

The cost is calculated according to the functional units, referring to the structure, including costs of materials, concrete, brick and mortar, and labor, considering one worker and a servant. The foundation is not considered since the foundation template is equal to either conventional construction or masonry.

3.1 *Scenario 1*

Table 2 shows the costs for the construction of the functional units for the first scenario. Variation is estimated as Variation = CC-M. Hence, the sign minus indicates lower costs for Masonry option.

Table 2, Comparison of costs for scenario 1

Functional	Exterior wall			Interior wall		
units	CC	M	Variation	CC	M	Variation
4 m	537.72	418.18	-22 %	278.66	237.60	-15 %
6 m	841.01	627.26	-25 %	486.06	356.40	-27 %
7 m	1011.00	731.81	-28 %	619.72	415.80	-33 %

For the functional units of exterior walls can be seen that the masonry construction is more economicfor spansstudied and cost reduction increases with increasing span. Cost reduction varies with openings 4 to 7 m settling for 22 to 28%. This is due to the change in the height of the beams, which increases with increasing span. The span changes two meters, from 4 to 6m, and then one meter, from 6m to 7m, however the cost variation is 3% for both intervals.

In the case of interior walls the tendency is more marked as the span range increases. There is a cost reduction from 15% to 33% asthe span increases from 4m to 7m. The variation appears more linear than in the case of the exterior walls although there are only three data.

The detailed costs for construction materials and labor are shown in the Tables 3 and 4.

Table 3, Comparison of material costs for scenario 1 (euro)

Functional	Exterior			Interior		
units	CC	M	Variation	CC	M	Variation
4 m	419.82	290.41	-31 %	201.66	163.51	-19 %
6 m	664.23	435.62	-34 %	358.79	245.27	-32 %
7 m	805.76	508.22	-37 %	464.75	286.15	-38 %

Table 4, Comparison of labor costs for scenario 1 (euro)

Functional units	Exterior			Interior		
	CC	M	Variation	CC	M	Variation
4 m	117.89	127.76	8 %	77.00	74.09	-4 %
6 m	176.78	191.65	8 %	127.26	111.13	-13 %
7 m	205.25	223.59	9 %	154.97	129.65	-16 %

The trend in the cost of materials is in accordance with the total costs. The materials costs have a higher weight than the labor costs. It appears that the labor costs in structural masonry are slightly higher in the execution of the exterior walls and slightly lower in the execution of the interior walls due to partial occupation of spaces for reinforced concrete beams.

3.2 *Scenario 2*

Table 5 shows the constructions costs of the functional units in the second scenario.

Table 5, Comparison of the total costs of the functional units for scenario 1 (euro)

Functional units	Exterior			Interior		
	CC	M	Variation	CC	M	Variation
4 m	537.72	418.18	-22 %	278.66	107.14	-62 %
6 m	841.01	627.26	-25 %	486.06	160.70	-67 %
7 m	1011.00	731.81	-28 %	619.72	187.49	-70 %

In the second scenario the costs remain the same for the outer walls, while for the interior walls costs become much more favorable for masonry construction. This means that small buildings up to two levels may benefit more from ceramic masonry, with a remarkable reduction of the costs of the interior walls 62 to 70% as the span increases from 4 to 7 m due to less necessity of structural stability in comparison to the first scenario.

The detailed costs for construction material and labor are shown in the Tables 6 and 7.

Table 6, Comparison of material costs for scenario 2(euro)

Functional units	Exterior			Interior		
	CC	M	Variation	CC	M	Variation
4 m	419.82	290.41	-31 %	201.66	33.05	-84 %
6 m	664.23	435.62	-34 %	358.79	49.57	-86 %
7 m	805.76	508.22	-37 %	464.75	57.83	-88 %

Table 7, Comparison of labor costs for scenario 2(euro)

Functional units	Exterior			Interior		
	CC	M	Variation	CC	M	Variation
4 m	117.89	127.76	+8 %	77.00	74.09	-4 %
6 m	176.78	191.65	+8 %	127.26	111.13	-13 %
7 m	205.25	223.59	+9 %	154.97	129.65	-16 %

In this scenario it becomes clear that the second scenario is more beneficial in the construction of the interior walls regardless of the outer walls as they must evidently have the same costs either in scenario 1 or 2. The interior walls in case ofconventional construction turn to be more expensive because of the concrete used for the pillars and beams.

4 CONCLUSION

This study compares the costs of exterior and interior walls of conventional construction, reticulated reinforced concrete structure and unreinforced masonry both with ceramic blocks. Functional units are defined with the same functional and physical criteria, structural, thermal and acoustic performance for walls with spans of 4m, 6m and 7m. The results show that in small buildings, up to two floors and spans up to 7 meters, the materialcosts can be reduced. Cost reduction is obtained for the outer walls at least 22%, while for the interior walls at least 62%. The results are applicable in residential and public buildings, such as health centers or centers of administration.The labor cost is slightly higher, indicating the more intense application of manpower. In the high unemployment societies, such as Portugal at the time being, this can result in higher rates of employment.

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Sustainable Daylighting Design in Southern European Regions

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ABSTRACT: Traditional daylighting approaches and the metrics used for their quantification (such as the daylight factor), have limitations that do not take into account the dynamic characteristics of daylight and in particular its energy-related effects and the influence of the occupants of the buildings in the final daylighting performance. This paper proposes an integrated method for the characterization and realistic prediction of the dynamic performance of daylighting based on the daylighting-hours indicator concept (Href) and on a daylighting-related behavioral model.

1 INTRODUCTION

The main purpose of daylight in buildings is to provide an adequate indoor visual environment that ensures the most adequate lighting conditions for the performance of visual tasks. These conditions should include: i) adequate lighting levels and distribution, ii) the guarantee of visual comfort for the occupants and iii) the more subjective benefits related to the use of natural light instead of artificial light and contact with the exterior environment through windows. Daylighting can also contribute to energy efficiency provided that its energy impacts are correctly assessed during the design phase of buildings. The energy-related aspects of daylighting are particularly important in regions with long and hot cooling-seasons, where non-overcast skies conditions prevail, which is the case of most of the south European regions and in particular of Portugal.

The traditional approaches to daylight in buildings are generally based on the Daylight Factor (DF) concept, which is useful in the characterisation of “worst case scenarios” of daylighting, but has limited capacity in the characterisation of the real daylight conditions throughout the year, essentially due to the intrinsic dynamic nature of daylight. In the present document a description of a new method for the characterisation of dynamic daylighting conditions is presented. In this study, the “dynamic characterisation” takes into consideration the following aspects: i) a dynamic representation of the natural luminous climate (based on the daylight-hour indicator method (Carvalho 1997, Carvalho & Santos 2000); ii) the guarantee of visual comfort for occupants; iii) adequate daylight metrics for the dynamic characterisation of the interior daylight environment; iv) evaluation of the energy related impacts of daylighting; v) the effect of the control systems (shading and electric lighting) and their control strategies; and vi) the effects of occupants on final and daylighting conditions (evaluated through a behavioural model). In this paper two of the fundamental aspects of the method are described: the daylighting-hours method and the behavioural model.

2 PREVIOUS RESEARCH

Several studies have been proposed to overcome some of the limitations of the more traditional approaches to daylighting, but most of them also have limitations in their application, in particular when taking into account the effect of occupants' motivations and attitudes towards the visual indoor environment and associated control systems (lighting and shading) in regions with prevailing clear or quasi-clear sky conditions.

Non-traditional methods of daylighting characterisation can be divided into 3 major categories: i) integrated methods; ii) energy impacts of daylighting methods and iii) behavioural methods. Some of the methods combine one or more of the characteristics referred to.

The characterisation of the energy impacts of daylighting in buildings have been addressed in different ways by different authors. The first consistent studies, developed by Crisp (Crisp 1977) and Hunt (Hunt 1980), were mainly concerned with savings in electric lighting energy due to the use of daylight in buildings. The authors took into consideration the effect of manual electric lighting controls in the potential savings using the probability of switching the lights on as a function of the time of the day and of the minimum daylight factor in the work plane. Lynes and Littlefair (Lynes and Littlefair 1990) addressed some of the limitations of Hunt's model and proposed a new method which is relatively simple and particularly useful in early building design stages. This method is based on the definition of a two-zone daylight model and on the concept of Average Daylight Factor (ADF). It also incorporates an adapted version of Hunt's "probability of switching" consistent with the ADF method. Although reliable and valuable, the usefulness of daylight factor-based methods in climates where non-overcast sky conditions prevail is rather limited.

The LT Method (Baker & Steemers 2005) is one of the most well-known simplified methods for the assessment of energy impacts in buildings. The LT Method provides the means to estimate the relative energy performance of different building design alternatives by allowing the desegregated prediction of energy use for heating, cooling and lighting. Based on sets of charts with the total and desegregated heating, cooling and lighting energy use, the numerical details of the models that originate those charts are not known, limiting its applicability to specific climatic, constructive and functional conditions. Additionally, the method relies on the transparent fraction of the façade to account for daylighting.

Published in the framework of the European Energy Performance of Buildings Directive (EPBD), standard EN 15193 (EN 15193 2005) includes a simplified and a comprehensive methodology for the assessment of lighting energy estimation in buildings that takes into consideration the potential lighting energy savings due to daylighting proposing a new indicator LENI (Lighting Energy Numerical Indicator) that quantifies the total energy used in a building or space for lighting.

More recent studies, and in particular those by Veitch (Veitch & Galasiu 2006; Veitch et al. 2008) and Reinhart (Reinhart & Voss 2003; Reinhart et al. 2006) propose more innovative methodologies which take into consideration the effect of occupants in the lighting use in buildings through the incorporation of behavioural models. Some of these methods also include the effect of the control of shading devices and new metrics more adequate for the dynamic characterisation of daylighting.

3 THE IMPROVED DAYLIGHTING-HOURS INDICATOR METHOD

A method for the dynamic characterisation of daylighting is herein proposed. The method addresses some of the problems identified in the previous sections. It takes into consideration the prevailing average climatic conditions, the guarantee of the lighting requirements (daylighting levels, absence of glare, the psychological benefits of daylight use and the visual contact with the exterior environment) in an energy efficient way and the attitudes and motivations of building users towards indoor visual comfort and control systems. The incorporation of these aspects in a global building design strategy is often the real challenge in any successful daylighting design process.

In Figure 1 a schematic illustration of the proposed method is presented. The "cores" of the method are the daylighting-hours indicator method and a daylighting behavioural model.

The characterization and representation of the luminous climate in Southern European regions is represented on illuminance charts (Fig. 2) and make use of data collected for Lisbon under the IDMP Programme (IDMP 2001) and additional information from Satel-light Joule project (Satel-light 2012).

The quantification of daylighting conditions (work plane illuminances, uniformity and glare) and the impact of shading systems (type, controls and patterns of use) in the energy use for lighting incorporates information from a behavioural module (typical patterns of use and behavioural profiles) and is based on an improved version of the Daylighting-Hours Indicators model (Carvalho 1997, Carvalho & Santos 2000), briefly described in the following paragraphs.

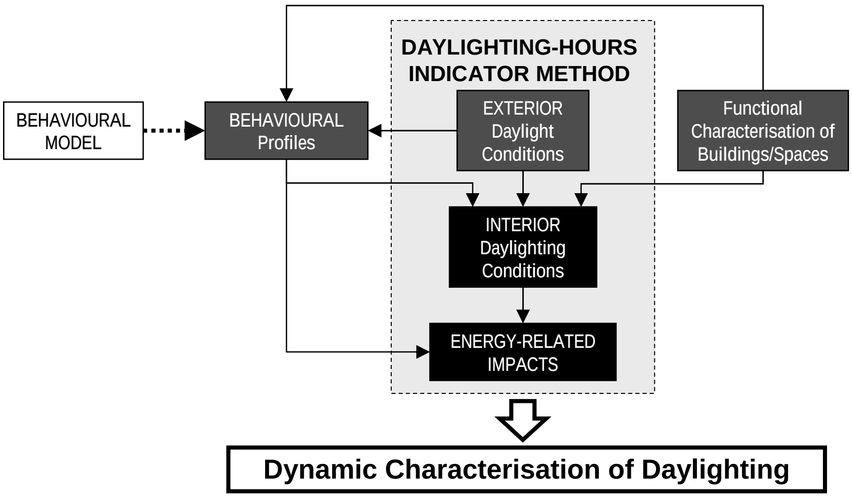

Figure 1. Schematic illustration of the proposed method.

The Daylighting-Hours Indicators (DHI) method enables the characterization daylighting availability in interior spaces in climates where clear skies and sunlight effects prevail. The indicator and its resultant method of calculation are intended to be used in southern European regions and, more generally, in regions where sunlight is important to daylighting performance. The indicator is called daylighting-hours indicator and may be used to compute the electric lighting use and to estimate energy savings due to daylighting. The climatic daylight information is graphically represented as illuminance charts.

The DHI are represented by the term Href, where ref refers to an illuminance value, and they are applied to a zone of a space. Daylighting-Hours can be defined as the average number of hours of the period of use of the space, during which daylighting illuminance levels at a point of a plan of an interior zone, which is representative of that zone, exceed the reference level - ref - and simultaneously visual comfort requirements are accomplished. If appropriate, zone-averaged illuminance values on different representative points can be considered. For instance, H300=1000 hours means that during the period of use, the representative daylighting illuminances exceeds 300 lx, during 1000 hours in average, per year, maintaining the visual comfort requirements.

The calculation method uses a model of representation of the daylight climate based on the following assumptions: i) external daylight conditions can be represented by sequences of periods without sunshine, and of periods with sunshine; ii) the average frequency of occurrence of periods with sunshine is given by the relative sunshine duration.

The calculation of DHI is first performed separately for the periods with sunshine and then without sunshine. The annual value is then computed weighting the results obtained for each type of period according to the relative sunshine duration data for the location.

The model also assumes that the ratio between the internal illuminances due to vertical glazing systems and the illuminances on the external surface of that glazing system is constant and equal to the value established for a standard CIE overcast sky. The minimum vertical illuminance (Ev_min) on the external face of a window required to produce an internal illuminance Ein at a point of a plane with a daylight factor DF (%) due to daylight coming from that glazing system is then given by Equation 1 (Santos 2011).

$$Ev\_\min = (Ein\ .\ 40\%) / DF(\%) \tag{1}$$

Using the previous expression the average number of hours during which the internal illuminances exceed Ein can be determined, by estimating the number of hours during which illuminances on the external face of the glazing exceed Ev_min. A set of Illuminance charts, as the one depicted in Figure 2, are used to perform these estimates. Illuminance charts are the representation, on a solar chart, of the average illuminances on different surfaces produced by skylight and sunlight for a grid of positions of the sun. In order to be able to consider separately periods with and without sunshine there are different charts for each type of these periods. For periods with sunshine there are also charts for global illuminances (skylight and sunlight) and for diffuse illuminances (to estimate the effect of external obstructions).

The calculation procedure for a particular daylighting-hours indicator (Href) is the following:

- Determination of the parameters that relate the interior illuminance Ein with the known exterior illuminances;
- Estimation of the daylight factor DF(%) at the point and plane under consideration;
- Determination of Ev_min, using Equation 1, considering Ein = ref;
- Definition of a characteristic pattern of use for the shading devices (bearing in mind the maintenance of the visual comfort conditions, the necessary solar protection and the occupants' behavioural patterns of control);
- Use of the appropriate illuminance charts, to estimate, separately for periods with sunshine and without sunshine, the number of hours per year during which the illuminances at the glazing surface exceed Ev_min;
- Scoring the number of hour-month points (Fig. 2) for which the above conditions are satisfied;
- Estimation of Href indicator combining results obtained for each period according to the annual mean relative sunshine duration value.

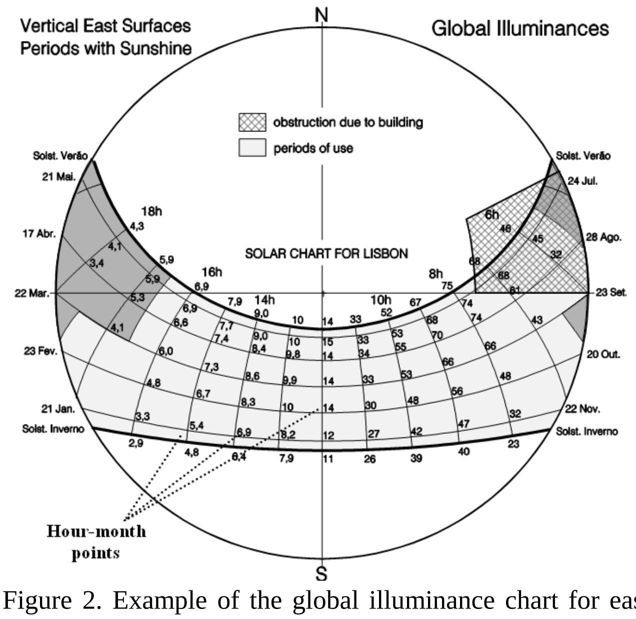

Figure 2. Example of the global illuminance chart for east vertical surfaces, for periods with sunshine with the hour-month points. The periods of use and the obstructions are also represented.

Manual calculations can be time-consuming due to the following reasons: presence of windows with different orientations, existence of complex geometrical external obstructions, and the need to take into account the daylight reflected by the ground that reach the different windows. In these situations a computer application was developed and is used. The improved method also includes the effect of occupants' preferences and attitudes towards daylighting and indoor environmental control systems (electric lighting and shading controls).

4 THE BEHAVIOURAL MODEL

4.1 *General aspects*

The present study seeks to overcome some limitations of the traditional perspectives of analysis of the luminous environment in buildings, using an interdisciplinary approach based on the assumption that the conventional objective (physical) characterization of indoor luminous environments have not, by itself, the ability to capture the subjective (sensorial) experience of individuals, which have a major influence on the actual final performance of buildings. In this sense, the inclusion of subjective aspects such as perceptions, expectations and behaviour of the occupants of buildings towards the luminous environment and the control systems at their disposal, will enhance the explanatory and predictive ability of more traditional analysis tools. As referred previously, the ultimate aim of the study is to include the behavioural aspects in a general model for the dynamic characterization of daylighting in buildings.

Several studies (Veitch & Galasiu 2006; Reinhart et al. 2006) have already pointed out the crucial influence of the occupants' attitudes towards their indoor environmental controls in the visual, thermal and energy performance of buildings. In fact, in order to anticipate the realistic daylighting and visual comfort conditions inside buildings its essential to have a solid knowledge on the typical patterns of use of shading and electric lighting. These patterns of use are directly related with the users' preferences and motivations regarding their indoor visual and thermal environment.

One of the most innovative aspects of the methodology herein presented is the integration of the occupants' motivations and attitudes towards daylighting and control systems in the model, through the definition of typical patterns of behaviour. These patterns have a crucial influence in the final indoor illuminances, and in the visual and thermal comfort and energy use in lighting. The behavioural module is being developed based on on-site observations of behavioural patterns in various buildings and by informal and formal surveys.

4.2 *Methodology*

The methodology of the study included the statistical analysis of a formal survey by questionnaire for the assessment of the individual lighting conditions (both natural and electric) in different spaces of several buildings selected as case studies. The formal survey was further complemented by informal surveys, on site daylight measurements, observations and additional informal surveys and interviews.

The post-occupancy surveys performed in the scope of this research comprised a set of 13 selected multifunctional, office and educational buildings. These buildings presented different functional characteristics (such as, window type and orientation, type of shading devices, type of electric lighting, among several others) and geographical/climatic location. Daily and seasonal sunlight variations were also considered. Electric lighting and shading devices control strategies ranged from manual to fully automated controls.

Surveys were based on a comprehensive structured questionnaire comprising seven thematic groups of questions: working place; luminous environment; windows/views; type and control of shading devices; type and control of electric lighting; visual tasks and social characterisation of the participants.

Subjective data was complemented by on site daylighting measurements, conducted according to a predefined measurement protocol. Relevant parameters, such as: room characterization; indoor illuminances at work plane level and for different vertical orientations (with different states of activation of the adjustable shading devices); outdoor illuminances, among others, were measured and observed for posterior analysis. Photographic records and complementary informal interviews helped to complete and validate/calibrate other collected data.

All 584 participants (54 % male, 46 % female, with ages ranging from 18 to 50) answered the questionnaire providing an extensive and representative amount of valuable information about their perception and behaviour related with the indoor luminous environment and effectiveness of existing indoor environmental control systems. More than 50 % of the subjects work places were located at a distance inferior to 2 m from the façade, thus increasing the potential use of daylight, but also the risk of glare (approximately 84 % used a computer for most of their working hours).

Objective Performance Indexes (OPI's) were defined in order to enable a better comparison, calibration and validation of the subjective data. These indexes result from the analysis of collected data and are being introduced in the dynamic daylight simulation model. One of the indexes (Daylighting Quality Index) was based on measured parameters (e.g. illuminances at the horizontal work plane and at four vertical orthogonal directions, one of them being the window direction) and was used to analyse and validate subjective data on the "quality of the luminous environment".

In the following section some of the objective and subjective outputs of this study are presented and commented.

4.3 *Results*

4.3.1 *Perception of the luminous environment*

When analysing separately the artificial and natural luminous environments an expressive difference was found between objective and subjective assessment of illuminance levels. In fact individuals in artificial lit environments are much more tolerant to the measured illuminance levels which are conventionally assessed as insufficient. This probably means that people are more demanding when working in daylight environments due to "added value" recognized to daylight beyond merely the satisfaction of visual task performance requirements. This conclusion is illustrated in Figure 3, which details a subjective appraisal of luminous perception of daylit work plane levels. Although a significant percentage of measured illuminance levels were less than 500 lux most of the participants considered that they were working under satisfactory luminous conditions (sufficient illuminance levels).

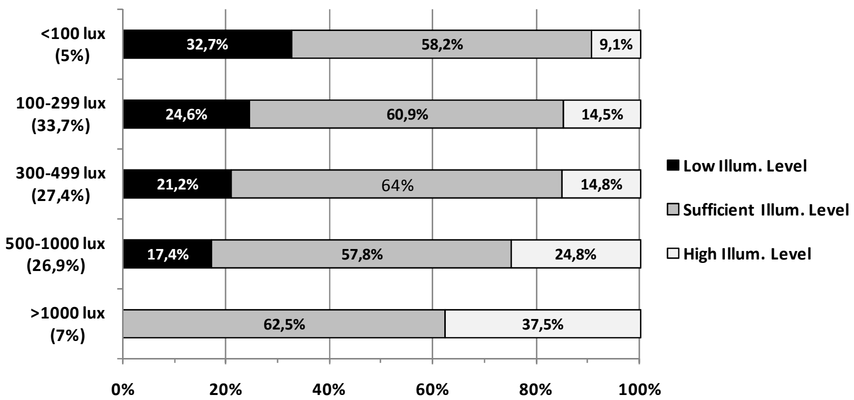

Figure 3. Subjective luminous perception as function of work-plane illuminance level

In the studied spaces glare due electric lighting does not constitute a matter of major complaint or dissatisfaction however, in spaces only with the electric lighting turned off, daylight glare is a cause of discomfort for 30% of participants, most of them working close to a window. The incidence of direct sunlight on a computer screens (70,7 %) or on the working plane (28,8 %) are pointed out as the major causes of high (43 %) to moderate (36 %) degree of discomfort.

Although this occurs mostly during clear sky conditions, a curious remark is that most of the complaints were recorded in spaces where manual operated and effective shading devices were available. The most probable causes for this apparent contradiction can be either their misuse or, eventually, the interference of their use with the general room daylight levels. Also, the main reasons pointed out for the use of the shading devices as glare mitigation is only secondary (63,4 %) compared with the protection from solar gains heat (78,2 %).

Several other important aspects of the study associated with the perception and preferences related with of the luminous environment can be found in reference (Santos et al. 2010).

4.3.2 *Attitudes and behaviours*

Regarding the attitudes and behaviours of the observed and analysed, several important aspects were found. In general, there is a significant discrepancy between the answers to the survey and the observed attitudes and behaviours. This aspect is particularly relevant in what refers to the patterns of use of adjustable shading devices. In analysing these aspects the observations and informal interviews were fundamental to "calibrate/validate" the formal survey results. In general, people tend to say that they adjust the shading devices more frequently than the observation demonstrated. Nevertheless, a strong correlation exists between the perceived degree of freedom in controlling the shading devices and the actual control. The orientation of the windows also has an important role on the state of activation of shading devices.

A comprehensive analysis of other important aspects of the study associated with the behavioural patterns of the occupants towards the shading and electric lighting systems and respective controls was also object of study (Santos 2011).

4.3.3 *A linked mechanisms approach towards a behavioural model*

The statistical analysis of the results of the surveys and of the on-site characterisations allowed the identification of important correlations between different variables (degree of control over shading devices versus satisfaction with the indoor environment, effectiveness of the controls versus adequate energy-saving attitudes, etc.).

The objective and subjective outputs of the field post occupancy surveys supplied the rationale to structure a hypothetical model establishing the links between users' perceptions and behaviours and luminous environment. In Figure 4 a structural equations model is presented representing the variables selected to measure all concepts in analysis relating indoor and outdoor lighting conditions; visual comfort and subjective appraisal of the luminous environment; building characteristics and users' behaviours and satisfaction.

The definition of the typical behaviour profiles are based on the Objective Performance Index denominated Dynamic Daylighting Score (DDS) which, in turn will establish different scenarios as inputs for the daylighting-hours indicator model.

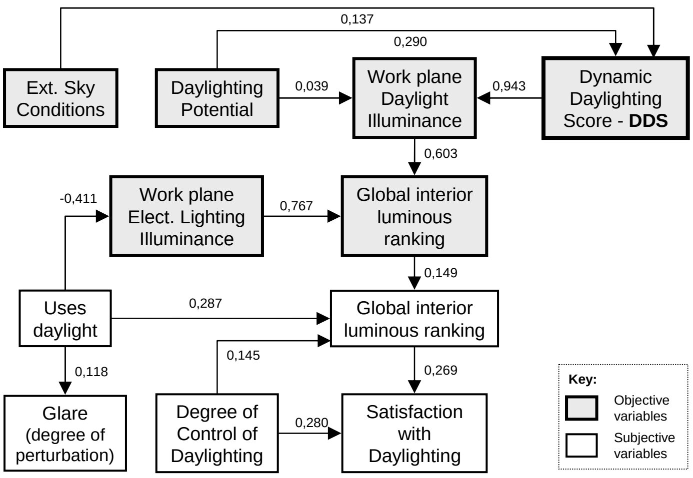

Figure 4. Diagram of the structural equation model obtained for describing the relevant relationships for an interdisciplinary approach (subjective/objective).

Further improvements through multivariate statistical analysis, testing and validation of this structural model will contribute to enhance the dynamic daylighting simulation model, namely by supporting the definition of typical realistic patterns of behaviour related with daylighting, electric lighting and shading and respective control systems.

5 CONCLUSIONS AND FURTHER WORK

In this paper, a methodology for the dynamic characterisation of daylighting was presented. The proposed methodology is particularly adequate for climates where the non-overcast sky conditions prevail and it is based on an improved daylighting-hours model and on a behavioural model. The outputs of the model will allow knowing, under realistic conditions (climatic, behavioural and functional) the effective number of annual hours that daylight can provide the lighting needs in luminous environment visually comfortable.

The following points summarize some relevant results of the study:

- Daylighting constitutes, in fact, one of the most referred factors that contribute to the creation of a pleasant and stimulating indoor environment;
- An expressive difference between objective assessment and subjective appraisal of illuminance levels was found;
- People are more demanding (less tolerant) when working in daylit environments because there is an "added value" attributed to daylight beyond the pure satisfaction of visual task performance requirements;
- In the studied spaces, sunlight glare is a cause of discomfort for occupants and also strongly correlated with complaints related to thermal discomfort;
- Although daylight control (shading) is considered an important factor for those who work in daylit spaces, it is often not adequately exerted, and the subjective appraisal and objective assessment strongly diverge;
- The knowledge obtained about the patterns of behaviour of the occupants supported the definition of Objective Performance Indexes that will be integrated in a dynamic daylight simulation model.

In the fields covered by this research, the statistical analysis revealed the clear advantages of an integrated study combining a multiplicity of relevant physical and psychosocial factors and highlighted the complexity of intervening phenomena.

Further work should be done so that the information resulting from the formal post-occupancy surveys must be analyzed in a more rigorous and consistent way improving the overall accuracy of the model. Comparison and validation against reference models should also be done.

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Moisture buffering and latent heat effects in natural fibre insulation materials

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ABSTRACT: In this study experiments were conducted to compare the moisture buffering performance of three Natural Fibre Insulation materials (hemp-lime, hemp-fibre, sheep's wool) alongside glass wool insulation, both with and without finishing materials (lime and clay plaster, and gypsum plasterboard). Samples were exposed to a cycle of step changes in relative humidity between 53% and 75%, changing every 12 hours in isothermal conditions. Their moisture buffering performance was then determined by their change in mass. Thermocouples were also placed on the surface and beneath the finishing material of each sample to record temperature changes due to the adsorption and desorption of water vapour.
The hemp-lime sample showed the greatest moisture buffering capacity, around double that of the hemp-fibre and sheep's wool. Adding the finishing materials greatly reduced the buffering capacity, with the clay plaster providing the most buffering, highlighting the need to place greater focus on the properties of finishing materials.

1 INTRODUCTION

The research presented in this paper forms part of preliminary laboratory testing for a project investigating the hygrothermal performance of insulation materials and their suitability for the retrofit of buildings.

In cool and temperate climates space heating can be a significant source of greenhouse gas (GHG) emissions. In the UK the heating of domestic buildings is estimated to be responsible for ≈14% of total emissions (Thistlethwaite et al., 2012; DECC, 2012). As demolition and replacement of old housing stock is organizationally complex, existing housing will remain in use long into the future; therefore the retrofit of these buildings must be a target for reducing emissions. Approximately half of the cavity-wall buildings in the UK have now been insulated, however, only ≈2.6% (DCLG, 2012) of the estimated 7.8 million solid-walled houses (Lonsdale et al., 2012) have been insulated due to the greater difficulty and expense of the work.

Typically the materials used for internal solid wall insulation are foam boards or mineral wool, with a vapour barrier placed between the insulation and a plasterboard finish. However, there is some concern that this method will result in an increase in moisture content of the wall either because the wall will no longer be able to evaporate moisture to the warmer interior (Künzel, 1998) or that water vapour could easily migrate through any perforations in the vapour barrier leading to interstitial condensation (Slanina & Šilarova, 2009). Also, inevitable thermal bridging will increase the likelihood of surface condensation, which could then cause mould growth leading to heath issues for the residents (Sedlbauer, 2001).

The use of hygroscopic materials has been shown to stabilise fluctuations in relative humidity (Simonson et al., 2004a; Shea et al., 2012), maintaining a healthy indoor air quality (Arundel et al, 1986). All Natural Fibre Insulation (NFI) materials are hygroscopic. Within their structure they have hydroxyl groups which will hydrogen bond with water molecules. The quantity of water adsorbed is related to the relative humidity of their environment, therefore they are able to stabilise the humidity of a room by adsorbing when the relative humidity increases and desorbing as it decreases.

NFI materials also sequester carbon taken up during photosynthesis within the building structure. Life cycle assessments, based on UK production, have shown that both hemp-lime (Ip & Miller, 2012) and sheep's wool (Murphy & Norton, 2008) insulation have a negative embodied carbon on installation. The embodied carbon of construction materials manufactured in the UK accounts for ≈ 8% of total GHG emissions (DBIS, 2010, p21), and while it is difficult to retrofit a house so that the heating load is reduced to zero, the embodied carbon has the potential to be below zero when using NFI materials.

It has been proposed that moisture buffering may reduce energy use through both direct and indirect effects on heating load (Osanyintola & Simonson, 2006). An indirect saving would be to achieve a healthy level of humidity with a lower ventilation rate or greater airtightness (Simonson et al., 2004b), therefore losing less heated air to the outdoors, and using less power to run the ventilation system. A direct effect on heating load would be the effect of latent heat exchanges caused by the adsorption and desorption of water vapour.

Osanyintola & Simonson (2006) examined the effects of the heat of sorption by comparing two simulations of a $12m^2$ bedroom in a Northern European climate, one with hygroscopic materials (wood fibreboard and cellulose insulation) and one without. Heating was set to maintain the room at 20-21°C during the heating season, and moisture levels were set to that created by two people sleeping at night. The simulation was based on empirical data described in Simonson et al. (2004a).

During occupation it was found that energy use was ≈10% lower in the room insulated with hygroscopic materials, due to heat of sorption. However, over the whole heating season it was nearly equal because when the relative humidity was decreased (people left the room) evaporative cooling increased energy use. Although, if heating controls were set to account for this it is possible that an energy saving could be achieved.

Qin et al. (2009) also investigated the effect of latent heat exchanges on heating load. This simulation differed, in that, the $20m^2$ test room was treated as an office space, with the heating on a higher setting during the day and lower at night, with moisture production during the day to mimic occupation. A wooden structure with plasterboard finish was compared to a non-hygroscopic finish (Aluminium foil). During occupation 6.5% less heating energy was required when including latent heat exchanges, and 4% overall. A second paper by the same authors (Qin et al., 2011) simulated a whole building occupied overnight. In this case during occupation 5.8% less heating was required when considering hygroscopic materials, and 3.8% less overall. Both simulations were validated with the International Energy Agency BESTEST data (Rode & Woloszyn, 2007).

As well as measuring the moisture buffering capacity of NFI materials this paper attempts to make an assessment of latent heat exchanges in the materials so that this data can be used to validate simulations investigating the effect on heating load.

2 METHODS

2.1 *Moisture buffering capacity*

The ability of each sample to adsorb and desorb water vapour was determined by exposing it to a cycle of step changes in relative humidity between 53% and 75%, changing every 12 hours, while kept in isothermal conditions of 23°C in accordance with ISO 24353 (ISO, 2008). The cycles were repeated until the amount of moisture adsorbed and desorbed was equal. The samples were pre-conditioned at 23°C and 60%RH.

Each sample had an exposed surface area of 200 x 200 mm with a thickness representative of the product (Table 1). All other surfaces of the sample were covered in aluminium foil to prevent any moisture transfer (Fig. 1b). The sample mass was recorded every minute to the nearest 0.1g using an electronic balance. The conditions were created by placing the sample in a climate chamber (Fig. 1a) with averaged vertical and horizontal air speeds of 0.38 m/s and 0.88 m/s. A windscreen was used to reduce influence of airflow. The temperature and relative humidity in the chamber were measured every 5 minutes using a Tiny Tag TV-4505 temperature and relative humidity probe.

Table 1. Sample and material properties.

Insulation	Surface finish	Insulation thickness	Finish thickness	Bulk density of insulation
		mm	mm	kg/m3 @ 23°C, 60%RH
Hemp-lime	Lime plaster	90	15	304 ±14
Hemp-lime	Clay plaster	90	15	304 ±14
Sheep's Wool	Gypsum plasterboard	100	12.5	19 ±2
Hemp fibre	Gypsum plasterboard	75	12.5	42 ±2
Glass wool	Gypsum plasterboard	100	12.5	10 ±1

The moisture buffering capacity ρ (g/m^2) was calculated using the formula:

$$\rho = \frac{m_a - m_d}{A} \quad (1)$$

Where,
m_a = Mass of the sample at completion of moisture adsorption process (g)
m_d = Mass of the sample at completion of moisture desorption process (g)
A = Surface area of sample (m^2)

The density of each insulation material was also measured at 60%RH and 23°C using an electronic balance that recorded to the nearest 0.01g.

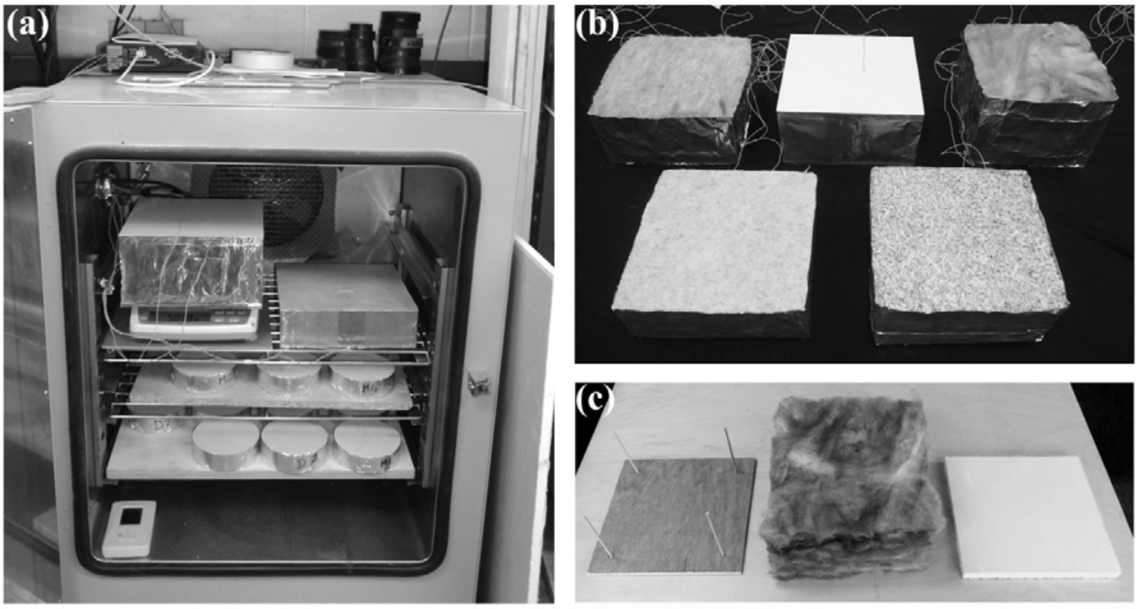

Figure 1. (a) Climate chamber experimental set up (b) 5 samples with attached thermocouples and aluminium foil (c) Plasterboard and glass wool sample before assembly.

2.2 *Latent heat of sorption*

The temperature at the adsorption/desorption surface, and at the interface of the insulation and finishing material was measured using T-type Welded Tip Thermocouples. For the hemp-lime samples holes were drilled using a 3mm drill bit from the base of the sample upwards, otherwise the thermocouples were secured to the materials using small strips of masking tape. For the fibrous materials the insulation was slightly opened up with a probe and the thermocouple pushed in 15 mm below the surface. Any small holes made for the thermocouples in the exterior of the sample were sealed up with aluminium tape. The calibration of the thermocouples had a standard deviation of between 0.08 and 0.14°C, over a range of 0-30°C.

3 MATERIALS

Both hemp based insulation materials are made from the stem of the hemp plant. The fibre is mechanically separated from the outside of the stem and the remaining central woody core (shiv) is used to make hemp-lime. The hemp fibre (95%) is blended with a polyester binder (5%) to keep the insulation to a specific density and treated with fire protectant. Sheep's wool insulation is produced by first cleaning (scouring) the wool and blending with a recycled polyester binder in the same proportions as with the hemp fibre insulation. Glass wool is made from recycled glass, which is heated to 1500°C and spun into fibre, then coated in a formaldehyde based resin as a binding agent. Plasterboard is made by making a gypsum slurry ($CaSO_4 \cdot 2H_2O$), which is formed into sheets, dried and cut into sections.

The hemp shiv was mixed 1:1.5 parts with lime binder and formed into a 90 x 600 x 600 mm slab. It was conditioned at 23°C and 60 %RH for 2 years, by which time it should have been fully carbonated. For the moisture buffering tests this slab was cut into 200 x 200mm pieces using a wood saw. Formwork was used to plaster the hemp-lime to provide accuracy in measurement. As per the manufacturer's guidelines, the plaster finishes comprised of a 12 mm undercoat and a 3 mm topcoat. For both samples the undercoat was allowed to dry at 23°C and 60 %RH for two weeks before applying the topcoat, which was given a further two weeks to reach equilibrium before testing.

Due to the compressibility of the sheep's wool and glass wool the plasterboard had to be fixed above the insulation using four 4mm diameter pieces of wood doweling set into a 5mm thick plywood base (Fig. 1c). Since wood is hygroscopic this may affect the results, however, it was assumed to be negligible due to the small quantity used. Also, in a retrofit using these materials wooden studwork would most likely be part of the structure.

The Lime plaster was produced by Baumit; Kalkin RK38 for the undercoat and Kalkin Glätt W for the topcoat. These comprise of a mixture of sand, hydraulic lime, and unspecified additives to improve workability and adhesion. The clay plaster was produced by Claytec. The undercoat is a mixture of natural clay, sand (≤ 2mm), and barley straw (≈ 30mm). The topcoat is natural clay, sand (≤ 0.8mm), flax fibres (≈ 15mm), and perlite. The hemp-lime and hemp fibre was provided by Lime Technology, the sheep's wool by Black Mountain, and the glass wool and gypsum plasterboard by Knauf.

4 RESULTS AND ANALYSIS

4.1 *Moisture buffering capacity*

Results of the moisture buffering capacity tests are given in Figure 2. Greater detail is given in Figures 3,4 & 5, which show the adsorption and desorption curves at dynamic equilibrium. Of the samples without a surface finish hemp-lime showed the greatest capacity; roughly double that of the sheep's wool and hemp fibre, while the glass wool provided no moisture buffering.

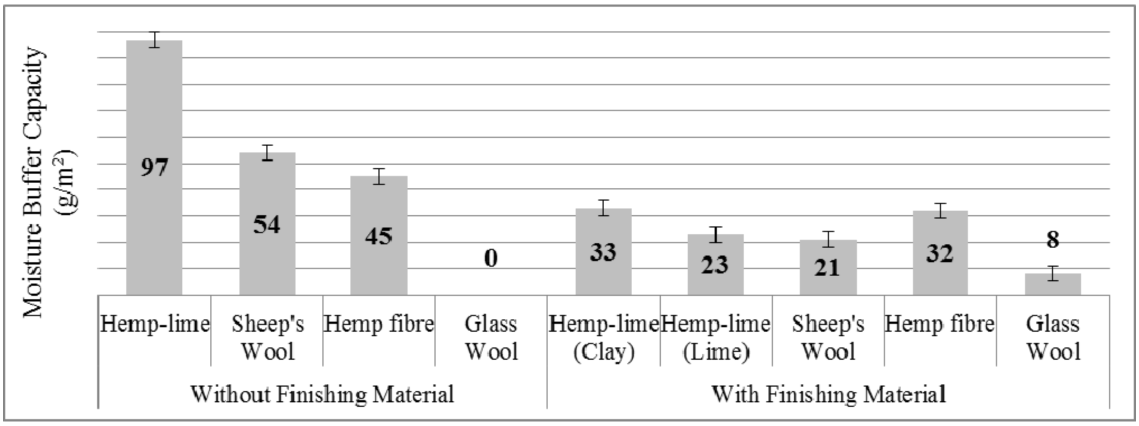

Figure 2. Moisture buffering capacity of the samples.

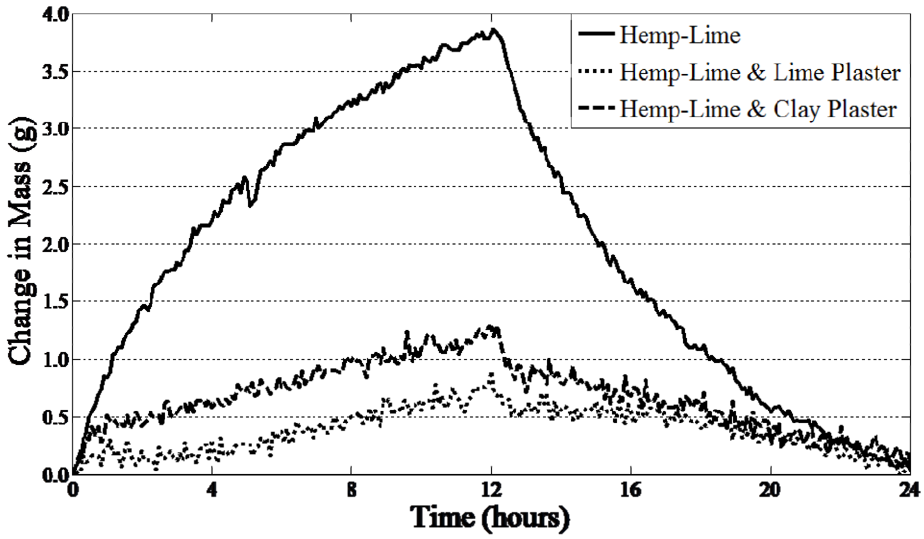

Figure 3. Moisture adsorption and desorption for the hemp-lime samples.

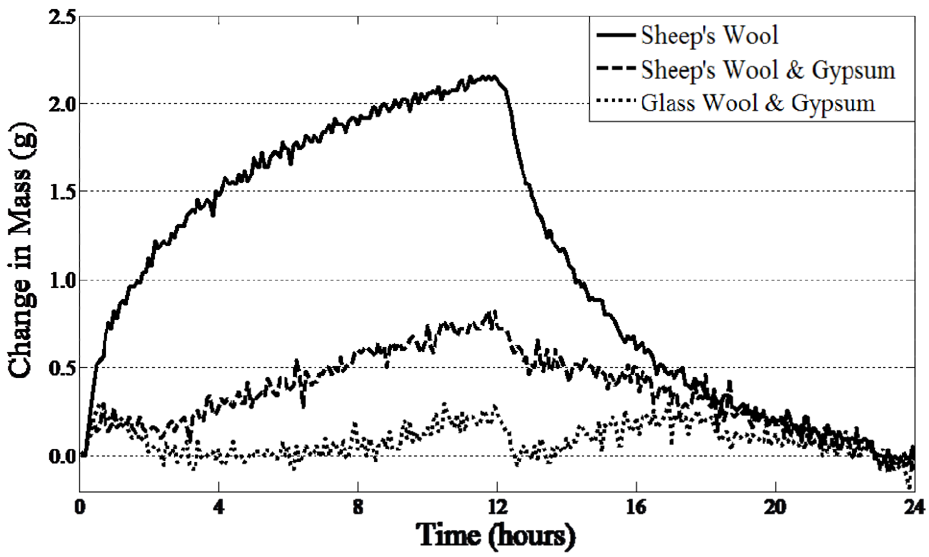

Figure 4. Moisture adsorption and desorption for the sheep's wool samples.

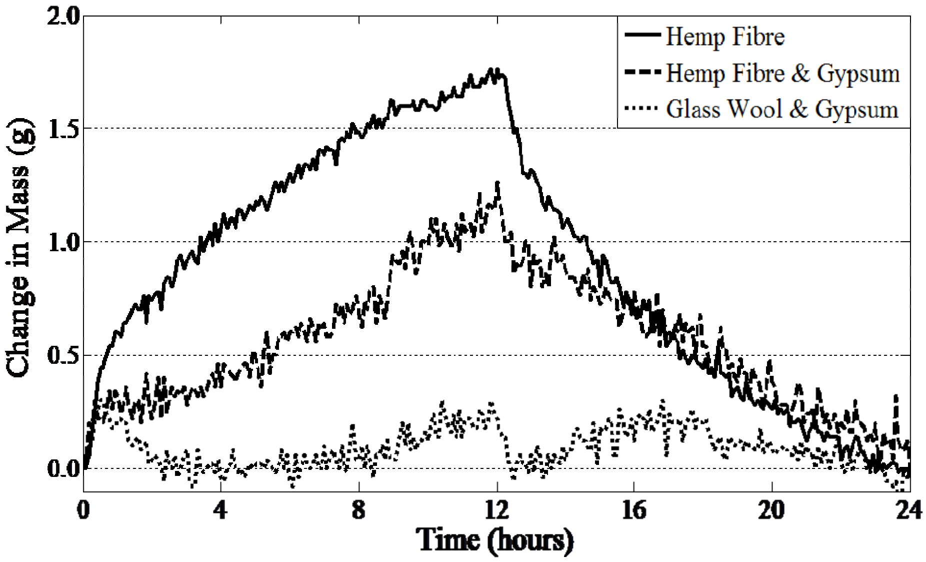

Figure 5. Moisture adsorption and desorption for the hemp fibre samples.

Hemp-lime has been previously tested (Collet et al., 2013), although the result is not directly comparable as it was conducted under different conditions using the NordTest Protocol (Rode et al, 2005). This uses a larger change in relative humidity (33%-75%), a shorter adsorption period (8 hours), and longer desorption period (16 hours). The sample was also more dense (430 kg/m^3). However, the test gave a similar result of 90 g/m^2.

Adding the surface finishes greatly reduced the moisture buffering capacity of the NFI materials. The surface finishes were less vapour permeable than the insulation materials, so reduced the depth that vapour could penetrate into the insulation. They also had a lower sorption capacity. As expected the clay plaster performed better than the lime plaster as clay has hydrogen bonding sites that will adsorb and desorb moisture. Glass wool was the only material that had its capacity increased by adding the finishing material as the gypsum plasterboard provided a small amount of buffering. Interestingly, the addition of plasterboard reduced the performance of the hemp fibre much less than for the sheep's wool.

Eckermann & Ziegert (2006) measured the moisture buffering capacities of 15mm thick samples of various plasters under similar conditions (50%-80%RH, 12 hour periods). Their result for lime plaster was equal to the result for hemp-lime with lime plaster suggesting that the hemp-lime had little effect on the buffering. They tested a range of clay plasters that gave buffering values between 32 g/m^2 to 67 g/m^2. The lower end of this range fits well with the result for the hemp-lime and clay plaster result, again suggesting the hemp-lime had little effect. They also measured a value of ≈ 9 g/m^2 for just gypsum plasterboard, comparing well with the result for glass wool and plasterboard presented here. This confirms that the sheep's wool and hemp fibre did influence the moisture buffering even below the plasterboard.

These results show how important the finishing materials are if the benefits of moisture buffering of NFI materials are to be fully realised. Finishing materials that are more vapour permeable and themselves hygroscopic should be further investigated.

4.2 *Latent heat of sorption*

When analysing this data it is important to consider that the thermocouples are only measuring a single point on the whole sample surface. There may be some variation across the surface, which is not detected by this method.

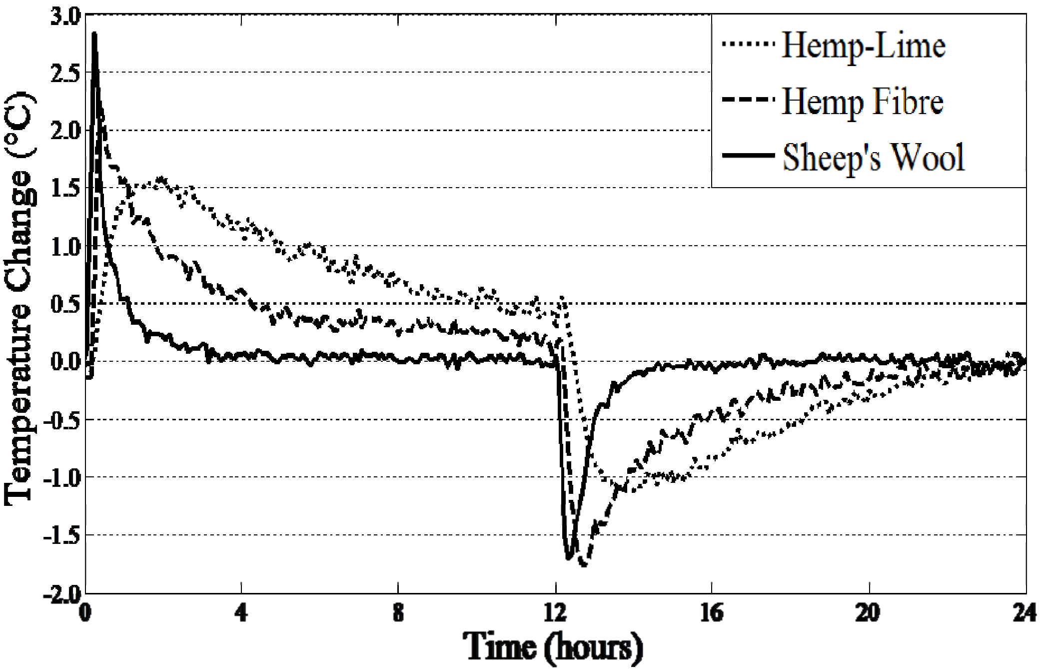

Figure 6. Temperatures at 15mm below the surface of the NFI materials without finishing material.

For all the samples the temperature below the surface underwent the largest change, which is likely due to the effect of air movement quickly cooling/heating the surface. Comparing the insulation without finishing material at 15mm below the surface (Fig. 6) there are clear differences: As the humidity was increased the sheep's wool heated rapidly 2.9°C, but quickly returned to ambient temperature; the hemp fibre took a little longer to increase 2.4°C, then cooling more slowly; the hemp-lime took 1 hour to increase 1.7°C and then maintained the highest temperature over the 12 hour adsorption period. During desorption the cooling follows a similar pattern, although the maximum temperature decrease was not a large as the temperature increase. However, the samples stay a little cooler for longer, so that overall the areas under (and above for desorption) the curve are approximately equal as would be expected at dynamic equilibrium. The differences in adsorption and desorption temperature changes may be due to a hysteresis between adsorption and desorption (Hill et al., 2009).

The differences in maximum temperature change are related to the water vapour permeability of the materials. The sheep's wool being of the lowest density (Table 1) should be most permeable; therefore water molecules will be able to reach its bonding sites most rapidly. The greater overall temperature difference of the hemp-lime is probably due to a greater sorption capacity, but also its greater volumetric heat capacity.

The effect of adding the finishing materials was to significantly dampen the temperature changes. However, they broadly followed the same pattern as in Figure 6. The temperature change for the hemp fibre was reduced to a range of 0.8°C to -0.6°C above and below ambient conditions at 15mm, while for sheep's wool it was 0.6°C to -0.5°C. Both hemp-lime samples maintained a temperature of ≈ 0.2°C above ambient conditions during adsorption, then decreased to ≈ -0.1°C as the relative humidity switched, gradually returning to the ambient temperature. However, these temperature changes are close to being within the error range of the thermocouples, and the amount of noise in the reading meant that it was difficult to show the results graphically.

James et al (2010) also measured the effect of latent heat during moisture buffering tests. A different protocol was used using adsorption and desorption periods of 24 hours each, and a change in relative humidity between 30%-70%. Three sections of 500 x 500mm plasterboard were layered on top of each other and the temperature and relative humidity were monitored between the sheets. The step change in relative humidity induced a temperature increase of approximately 0.5°C, the same as the temperature change recorded for the glass wool with gypsum plasterboard finish. However, it took 4 to 5 hours rather than the 8 minutes shown here, which could be due to the layering of the plasterboard.

5 CONCLUSIONS

When testing the NFI without their finishing material the hemp-lime showed the greatest buffering capacity, double that of sheep's wool and hemp fibre. However, plastering the hemp-lime greatly reduced its capacity, with the clay plaster performing the best due to its own sorption properties. The gypsum plasterboard provided a small amount of buffering capacity. It reduced the buffering capacity of the hemp fibre to a lesser extent than for the sheep's wool, but both materials were still able to be active.

These results highlight the importance of the finishing material covering hygroscopic insulation materials if their moisture buffering capacity is to be used to improve the internal climate of a building. Future testing will involve investigating finishing materials that are more vapour permeable and have hygroscopic properties.

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Potentialities of using PCM in residential buildings in Portugal

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ABSTRACT: In the past few years the energy crisis has been a big topic around the world and many studies have been made to improve the efficiency of energy use. One of the research areas is the building sector and his heating and cooling systems. Constantly changing weather has a large effect on room temperatures and thermal comfort of residents. Controlling devices and appliances are consuming a large amount of energy to keep the temperature within the comfort range. This work reviews the Phase Change Materials (PCM) use in new and refurbished buildings to decrease the energy consumption.
PCMs can be used in different structures like roofs, walls and floors and by correct placement the maximum potential may be achieved. The main objective is to stabilize the temperature fluctuations inside and reduce the energy use of heating and cooling systems. This study takes in consideration also the financial matters and additionally there is a short review of the possible application of PCM in northern countries.

1 INTRODUCTION

Energy consumption with heating and cooling systems in buildings has increased remarkably during the past few years. The constantly growing demand of energy is also increasing the fuel consumption and carbon dioxide (CO_2) emissions. To limit this instance more sustainable solutions need to be found. One reason for the increasing energy use in buildings is the growing amount of lightweight buildings that are built. They are less expensive and faster to build but at the same time they are more vulnerable for heat fluctuations. The lack of thermal mass can be recognized as high peak loads during cold and hot periods and further in high energy consumption (Cabeza et al. 2011, Castell et al. 2010, De Gracia et al. 2013, Evola et al. 2013, Farid et al. 2004, Fraser 2009, Alqallaf & Alawadhi 2010, Menoufi et al. 2013).

Thermal mass is the materials ability to store heat. For example concrete has a good ability for this because of its high density and heat capacity. Massive structures warm up and cool down slower than the surroundings and stabilize temperature fluctuations inside buildings. Phase change materials (PCMs) can be used to increase the thermal mass of lightweight buildings. PCMs can prevent overheating and lower the thermal peak loads and further decrease the demand for heating and cooling.

The system is environmentally friendly because it uses natural thermal energy to function. Because of the high safety regulations in building industry only a few PCMs can be used. Different materials and compounds are being studied to further improve potential energy saving properties of the PCMs. PCMs might be an easy and efficient solution for decreasing the energy consumption in buildings.

The objective of this work is to study the functionality of a phase change material and examine the possible benefits of using different PCMs to improve the energy efficiency of buildings.

2 PHASE CHANGE MATERIALS

2.1 *PCM Features*

A phase change material is a material that has ability to store and release thermal energy (Cabeza et al. 2011, Menoufi et al. 2013, Zalba et al. 2003). The basic idea of PCM is to reduce temperature fluctuations. PCM acts as thermal inertia without increasing significantly the weight of the building, reducing the structural needs and moderating thermal stresses. The goal is to prevent overheating, shift down peak-loads and reduce energy consumption.

PCMs efficiency is based on the latent heat method while most construction materials function with sensible heat storage (Farid et al. 2004, Tyagi & Buddhi 2007). In the latent heat method the heat storage and release occurs isothermally providing much higher storage density within smaller temperature difference than in the sensible method. Materials that have a high thermal conductivity have also high heat transfer rate. Even though most of the PCMs have low thermal conductivity enhancement applications can be used to improve heat transfer in the latent thermal storage systems.

PCM works in cycles. For applications PCMs phase transition is usually from solid to liquid and vice versa (Tyagi & Buddhi 2007). First the PCM absorbs heat from the surroundings and starts to melt, storing thermal energy. PCM compounds have different melting temperatures and the selection is done according to the requirements of the thermal operation range. On the second stage the PCM starts to solidify releasing the stored heat to surroundings. For the best functionality the cycles should be swift and completed each time. During a phase change the molecules are rearranged and enthalpy change occurs. The process enables PCMs to absorb or release thermal energy with high density and this feature is used to stabilize and control the temperature fluctuation.

PCMs are often divided into organic and inorganic compounds (Cabeza et al. 2011, Evola et al. 2013, Menoufi et al. 2013, Tyagi & Buddhi 2007, Zalba et al. 2003). Advantages for the organic PCMs are non-corrosiveness, low or none subcooling and chemical and thermal stability, but they have lower thermal conductivity, lower phase change enthalpy and present flammability risk. Inorganic PCMs have greater phase change enthalpy and conductivity but they are more vulnerable for subcooling, corrosion, phase separation and have a lack of thermal stability.

Usually PCM has to be encapsulated because during the phase change from solid to liquid the melted PCM could drain away and be misplaced (Cabeza et al. 2011). Encapsulation provides also larger heat transfer area and reduces the reactivity to outside environment. The two main encapsulation techniques are macro and microencapsulation (Farid et al. 2004, Zalba et al. 2003).

Different PCMs may have some inconvenient features that can risk the functionality or safety. Such features can be subcooling, segregation, materials compatibility or other technical problems (Cabeza et al. 2011, Farid et al. 2004, Zalba et al. 2003). The most limiting feature for the use of PCMs is the long term stability and the number of cycles that the PCMs can carry out without any decrease in thermal properties (Cabeza et al. 2011, Farid et al. 2004, Zalba et al. 2003).

The first studies using PCMs were made four decades ago with houses and storage tanks (Tyagi & Buddhi 2007). Improvements were to be made in living environment because especially lightweight residential buildings have low thermal mass and are vulnerable for high thermal fluctuations. With electrical heating and cooling systems this results in high energy demands and occasional peak-loads.

Although PCM substances are widely studied only few compounds make it through to commercial level (Cabeza et al. 2011). The materials are carefully tested to ensure safety and functionality. The materials service life is also estimated for the product to be beneficial for the consumers.

One of the major issues affecting usage and selection of PCMs is the financial matters. The cost of different PCMs vary highly and the building materials containing PCM are usually much more expensive than the ordinary ones.

2.2 *Building with PCM*

PCMs have been studied and tested for decades to be a part of heating and cooling systems in buildings and most of the results show a positive effect on energy performance. PCM usage in buildings is mainly based on solar energy that rely on the PCM's ability to store solar energy during day time and release gained heat during night (Tyagi & Buddhi 2007). Building with PCM is one of the most foreseeable applications of PCMs and in the future the method may decrease highly the heating and cooling energy use.

2.3 *Direct and indirect gain*

Solar energy gain can be direct or indirect (Tyagi & Buddhi 2007). Direct gain comes through buildings structures such as windows, doors or glass walls. The solar radiation or insolation can also be reflected from nearby surfaces like water or plate roofs as an indirect gain. Direct gain is more efficient than indirect but direct ultraviolet radiation may cause damage to the surfaces of objects and layers. In indirect gain concept structures like Trombe walls, water walls, trans wall or solariums are used to prevent the direct radiation from entering the living space. These methods are used when the fluctuations are above the comfort level and living space is vulnerable for overheating. The idea is to store excessive heat to heavy materials and keep the temperature tolerable. PCMs are used in the same purpose. PCM does not have to be in direct contact with solar radiation because it can absorb heat from surroundings and ambient air. The heat transfer is just a little slower in indirect gain than in direct gain concept.

Insolation varies during seasons and usually the yearly quantity of radiation is estimated and utilized in the design of buildings with PCMs. The seasonal changes have a large impact on the thermal loads and for the need of thermal storage.

2.4 *Area and thickness of PCM*

When using PCMs the placing and the amount of used PCM are to be estimated for the optimal functionality. Depending on the PCM’s properties the total surface area covered with PCM and the thickness of the PCM layer are calculated to fully utilize the heat storage capacity. Some PCMs cannot function as thick layers because the heat cannot reach and activate the furthest particles and therefore these types of PCMs need a large surface area in order to fully function.

2.5 *Structures*

PCMs can be used in new and refurbished buildings and since it has a large heat capacity it is an easier option to increase the thermal mass of lightweight structures (Fraser 2009). PCMs are often used in lightweight elements to facilitate installation. This also allows the possible replacement of PCMs in case of deactivation or damage. For example wallboards are relatively cheap, easy to install and commonly used in building industry and therefore suitable underlay to attach PCMs. Other structure examples could be a Trombe wall, PCM shutters or other more complex systems that may include applications such as heat exchangers or air conditioning (Evola et al. 2013, Tyagi & Buddhi 2007, Zalba et al. 2003). The structures are prepared so that the PCM does not cause changes to the structures such as expansion or bending while operating (melting and solidifying). PCMs can be placed almost in any surface of a house: floor, walls, ceiling, doors, shutters etc. (Tyagi & Buddhi 2007). In order to ensure the optimal benefit the surface with PCM must be clear of any insulating or blocking materials that might have a negative effect on the heat transfer.

Safety issues become more and more restrained every year to prevent hazards and to ensure safety. Structures with PCMs cannot jeopardize or cause any harm to building or occupants. To carry out the building requirements PCMs are examined carefully to ensure chemical balance, fire safety, non-toxicity and to prevent any other harmful features that may risk safety (Cabeza et al. 2011, Zalba et al. 2003). Aesthetic appeal is also taken into account in the design of the space.

3 METHODOLOGY

A simple study has been made to test out the effects and possible benefits of using PCMs in buildings. The testing takes into account the placing, melting temperature and the functioning of the PCM with and without HVAC system. Also the room and appliances were optimized.

The comparison was made by examining the room temperature and energy consumption. The testing was made in three sections. First one was simulating a test capsule without any PCM. On the second and third sections two different PCMs were used to see the possible differences.

3.1 *2.1 Simulation Program*

The study was made with computer simulation of a space with and without PCM. The simulations were made with Energy Plus software (version 8.0.0.007) and the design with Google Sketch Up plug-in (version 8.0.16846). Energy Plus was used as the simulation tool for this study as it has the capability to simulate phase change material in the building envelope (Pederson, 2007).

The target area is located in the Northern Portugal and the software (Energy Plus) weather file of Porto was used as the climatic conditions. The outside temperature varies from 0ºC to 31.1ºC, the average being 14.3ºC.

3.2 *Room Specifications*

The subject was approached using a simplified model and the test simulation was made for a typical living environment. The target space is a single room flat for one person and this test capsule presents one room in a residential building or in an apartment house. This design was chosen to avoid excessive simulation run time and to perform the analysis under controlled conditions. The dimensions of the test capsule are shown in Figure 1.

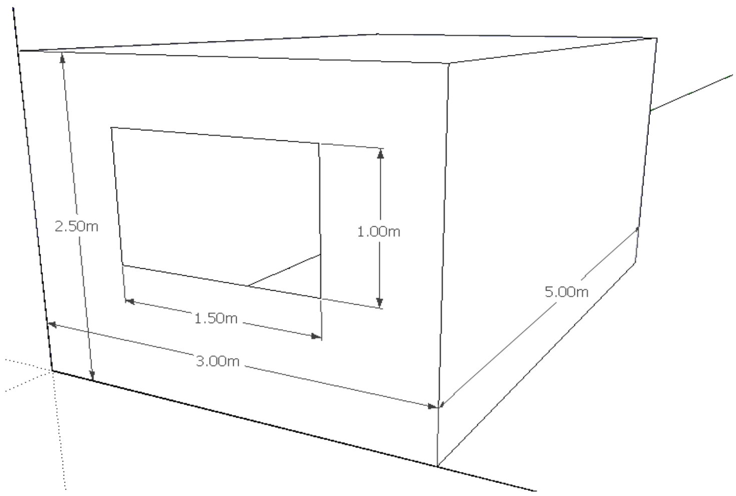

Figure 1. Test capsule sizes used in simulations (SketchUp).

The room has a depth of 5.0 m, a width of 3.0 m and height of 2.5 m. The window is 1.0 m high and 1.5 m wide facing south with a shading system for the warm periods. The construction is made with conventional structures and layer thicknesses of a residential building in the location area. All the walls and the roof are considered as exterior surfaces and the capsule is founded on ground level. The structure layers are:

- Wall: 220 mm hollow brick, 66 mm fiberglass, (PCM), 12 mm plasterboard
- Floor: 200 mm concrete, 66 mm fiberglass, (PCM), 12 mm wood cover
- Ceiling: 20 mm roof deck, 66 mm fiberglass, (PCM), 12 mm plasterboard
- Window: metallic frame with thermal cut; layers: clear 6mm glass, air 3mm and clear 6mm glass

The HVAC system for the room is an ideal system with 100% convective air system and 100% efficiency. The system does not have any duct losses or capacity limitation. The building mechanical system was set up to maintain the indoor temperatures above 18ºC (on winter) and under 25ºC (on summer). The system is running 24h per day or when needed.

3.3 *PCM Characteristics*

For the PCMs two commercialized products were chosen. The materials are placed under the surface layers. The products are introduced in the following (Delta-Cool, 2013; Dörken, 2013; Smartboard, 2013; Mariager, 2013):

- Delta-Cool by Dörken is salt hydrate that comes in small (4kg) packages and these "pouches" of PCM are usually placed on top of ceilings or under floors etc. (thickness 20 mm, density 1550 kg/m^3, specific heat 2450 J/kg-K, price 130 €/m^2).
- Smartboard from BASF (marketed by Knauf) is a gypsum board with microencapsulated paraffin and used as a wallboard itself (thickness 15 mm, density 766.7 kg/m^3, specific heat 1200 J/kg-K, price 50 €/m^2).

4 RESULTS

The results showed that it is possible to improve the thermal conditions inside the buildings.

4.1 *Placing*

For this room the optimal placing for the PCM according to the simulations performed is on the walls. The placing on the floor or ceiling results less effective. The hard floor cover is used to prevent damage but it decreases the effectiveness by 1-3% and when the PCM is placed on the ceiling the heat gathers up keeping the PCM melted.

Overall without the HVAC system the PCMs are stabilizing the thermal fluctuations and the room temperature is increasing on yearly average about 5°C regardless of the placing or the material used. The results also show that the salt hydrate has better thermal performance than the paraffin.

Figure 2 shows the temperature differences inside the room (demonstration day: 5th July). The room was set with a shading system for the window and no HVAC or ventilation system was used on the simulations. The PCMs with melting point around 24ºC are placed on the walls under the plasterboard.

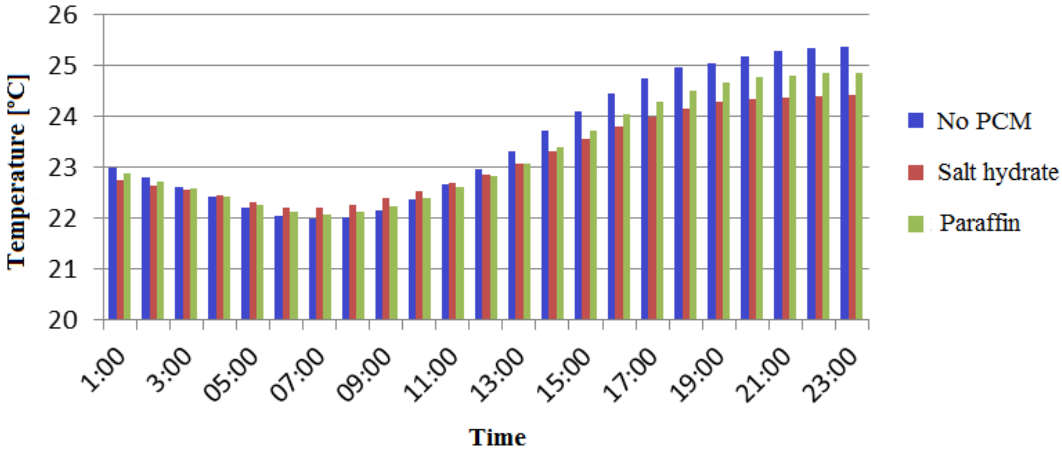

Figure 2. Temperature fluctuation in the room when the PCM is placed on the surfaces of the eastern (7.5m^2) and western (7.5m^2) walls under a 12mm plasterboard.

4.2 *Melting Point*

To reach the optimal thermal performance calculations were made to test out different melting points of the PCMs. The melting point was dropped by one degree at a time starting from 24ºC and the lowest being 19°C. At every point simulations were made and results compared to find out the optimal melting temperature.

In the test capsule the optimal melting temperature for the salt hydrate was around 21°C as for the paraffin the optimal melting point was around 23°C. The PCMs are subscribed as S21 (salt hydrate, melting point 21ºC, enthalpy of fusion 158kJ/kg) and P23 (paraffin, melting point 23ºC, enthalpy of fusion 110 kJ/kg).

4.3 *Energy comparison*

The room was set up with the original structures, shading system for the window, HVAC system set from 18°C to 25°C, ventilation set on night cooling during summer, 0.6 ACH (air changes per hour) and the PCMs placed on the walls.

The study of the test capsule showed that, in each case (test capsule with S21 and with P23 compared with the test capsule without PCMs), about two thirds of the total energy demand was cooling (66%) and one third heating (33%).

The total energy consumption for heating and cooling without PCMs was 18.6 kWh/m^{2}year. With S21 the total energy consumption decreased to 14.3 kWh/m^{2}year and with P23 to 17.4 kWh/m^{2}year. The comparison for yearly energy consumption is shown in Figure 3.

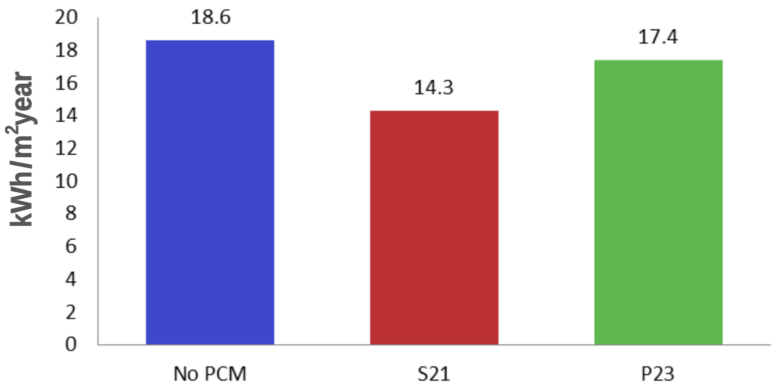

Figure 3. Energy consumption of the test capsule (kWh/m^{2}year).

As Figure 3 shows the PCMs are functioning correctly and clearly reducing the yearly energy demand. The salt hydrate (S21) reduces the energy consumption by 22.9 % and the paraffin (P23) by 6.4 % on the yearly average.

4.4 *Financial aspects*

The last evaluation was made by the material costs. The average cost found for the salt hydrate was 130 €/m^2 and for the paraffin 50 €/m^2. As the PCMs reduce the energy needs the financial savings can be calculated and compared to the market prices.

For the salt hydrate the annual savings are 8.96€ and for the paraffin 2.50€ (considering that the HVAC system is running 24h with an efficiency of 100% and the energy cost being 0.1405€/kWh in the target area).

The total cost for the salt hydrate is 1950€ and for the paraffin 750€. The prices are high when compared to the savings and it is not cost efficient to use the PCMs in the defined conditions.

Additionally calculations were made to find out what would be the reasonable price for the products to be beneficial. The expected service life for both PCMs was assumed to be 20 years and that the PCM should pay itself back in 10 years to cover the total expenses (Kosny et al.2013). The target price for S21 was 5.97 €/m^2 and for P23 1.66 €/m^2.

With the salt hydrate the real price for the product is over 20 times more expensive and with the paraffin even 30 times more expensive than the target price. This means that the payback time for each PCM would be much longer than the expected service life.

4.5 *Could the method be used in the northern countries?*

Climatic conditions in the northern countries are far more demanding than in the research location. The outdoor temperature varies highly from -30 to +28°C and for example in southern Finland the amount of months when the outdoor temperature reaches or overcomes the comfort level are limited to only three and the daily temperatures vary from +5°C to +26°C. The northern parts of the country are even cooler and there is practically no need for cooling systems in residential buildings or danger for overheating.

The building shells have thicker insulation layers and the house building standards are very strict to ensure the protective aspects of the building and the materials are chosen in different ways to withstand the climatic challenges. Mainly the structures are designed to prevent the heat leaking out. The material's R-value indicates the heat flux density (heat transfer per unit area per unit time) and it is used for a unit value of any particular material. For example the placing and the size of the windows and other structures or materials which have poor thermal resistance are chosen carefully.

As described before, the PCMs need heat fluctuations to function and as the thicker insulation and higher thermal mass stabilize the room temperature and the long winter period keeps the temperature low, thus there is a smaller rate for the PCMs to operate. The cycles are not rapid and the PCM stays in one phase for longer periods making the functioning less efficient.

However, instead of placing the PCMs on structures they could be combined with some other solar gain systems for example water tanks of thermal solar panels and associated to heating systems to increase their thermal capacity. These solutions might be more efficient and the PCMs could be used also in the northern climates.

5 CONCLUSION

Studies show that PCMs have a clear positive effect on the room temperature stabilization and energy saving. It is an easy way to add thermal mass to buildings without increasing the total building weight and onwards lower the heat fluctuations. However, the energy storage system development still has some major practical difficulties such as long term thermal behavior and stability. The problems with the cycling, phase segregation and subcooling are not yet completely solved and the low thermal conductivity and suitable melting temperatures limit the usable amount of the PCMs.

Altogether the PCMs stabilize the room temperature and facilitate thermal stresses. The placing and volume of the used PCMs should be carefully designed and optimized depending on the target space and heating and/or cooling needs. Also the functionality should be secured and the estimated service life should be taken into account.

In households without HVAC systems PCMs increase the average room temperature and reduce high thermal fluctuations. The results show 5 ºC increases in the average room temperature. In households with HVAC systems the PCMs reduce peak loads and decrease the energy consumption in both heating and cooling demands. The results show a clear decrease in the energy consumption (salt hydrate 22.9%, paraffin 6.4%). However, the PCMs cannot function during cold periods if the melting point is not reached especially in houses without heating system. Also, to prevent overheating and to ensure proper cycling shading systems and/or ventilation/night cooling are recommended on hot periods.

The results also show that the purchase prices are higher than the annual savings and the payback time is far too long to benefit financially from the use of the PCMs.

Thus, the main problem with PCM use in building industry is the financial matters. Even though the commercialized materials are safe and easy to place or combine with building materials they multiply the material costs making the total prices too high for the consumers. The companies guarantee long life expectancy for the products but as the payback time is long and the possible damage or decrease in the functioning the investment might not be reasonable.

However, it is important to get the consumers interested in these energy saving matters and possibilities with new materials. The next step is to further study PCMs, get the prices more accessible, get the products used in the building industry and with sales get more feedback of the materials and functioning.

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Home automation controller for a water-flow window

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ABSTRACT: Facing the EU energy efficiency and legal scenarios related to buildings new sustainable advanced concepts for envelopes are required. These innovative designs must be able to offer anelevated level of energy efficiency based on a high performance architecture. According to this, smart glazings, and particularly active water-flow glazings, represent a promising alternative to other solar control glazings, since they can reduce the building energy demand avoiding well known drawbacks as high cost, glare problems and high response time that affect to other smart glazings. This kind of glazing, as any other active one, needs to be operated by a control system. In order to operate a water-flow based window installed in a test box, a new controller based on an inexpensive microcontroller board has been developed. Significant energy savings for test boxes are gained.

1 INTRODUCTION

Glazed surfaces offers to building users natural light and the possibility of having external views at the same time they are protected from uncomfortable external ambient conditions. Those characteristics make them very appreciated by buildings users. However, from a thermal point of view, especially when considering latest EU regulations regarding energy efficiency in buildings (2010/31 UE) (EU, 2010), becomes evident that windows are one of the key elements that need to be improved in a significant way (Balaras et al. 2000)to achieve Near zero energy buildings (nZEB). It is known that blocking part of the incident solar radiation over the windows is an efficient way to avoid excessive solar gains(Eicker et al., 2008). On the other hand, water-flow windows, which consist of a double glass pane window and a circulating water chamber between the two panes, uses water properties to absorb a part of the solar radiation. This kind of smart glazing is a promising alternative since theynot only reduce the incident radiation that penetrates into the room, but also could be easily integrated with renewable energies.However, the same as other smart windows, as electrochromic or photochromic ones, a control system is required to assure that the system works properly. The need of usinga home automation controller for these kind of systemsis implicitly accepted (Chow, et al., 2011, Gil-López, and Giménez-Molina, 2013), and the minimum parts required for it has been analysed (Lauret et al., 2010). Moreover, a proposal about the feasibility of making a controller based on an Arduino board has been suggested(Anglés, and Lauret, 2009).Based on this idea,a new home automation controller has been designed and built from scratch and tested in a water-flow window prototype test box.

2 OBJECTIVES

In order to analyse the real performance of a smart window with a circulating water chamber, a pair of small test boxes has been tested. One of these two test boxes owns a water-flow window (Figure 1) while the other one, which is used as a reference test box, uses a common simple soda-lime glass. Both of them have been tested under real weather conditions in Technical University of Madrid.

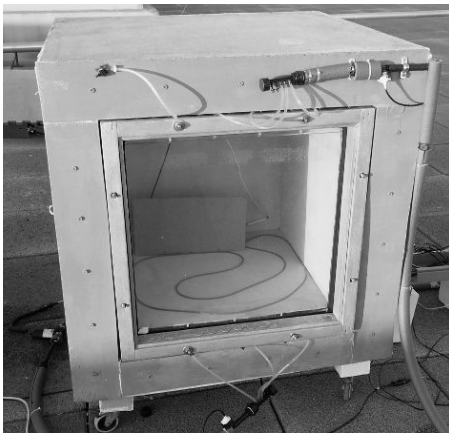

Figure 1. Water-flow window test box

According to the thermal comfort standards (ASHRAE, 2009) and previous tests, some parameters like comfort temperature limits,water flow velocitywerepreviously set.

The aim of the experimental tests is to evaluate the thermal performance of the water-flow window.To achieve that, the test box which uses the water-flow window works according to the programmed operations managed by the home automation control system. This system decides about the control actions depending on the measured variables as inside test box temperature or external ambient temperature. To assess the system performance, inside air temperature is measured in both test boxes.

3 EXPERIMENTAL ASSEMBLY AND OPERATING MODES

In the winter season configuration the experimental assembly is formed by two test boxes, one thermally isolated water tank, one pump, one solenoid valve and three temperature sensors, as shown inFigure 2.

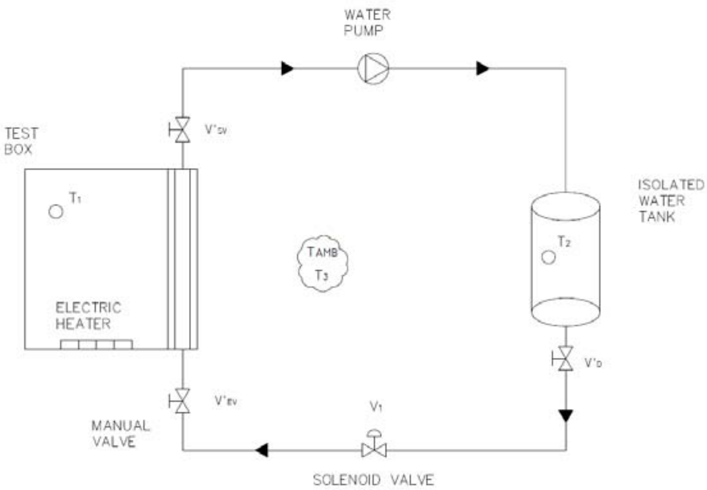

Figure 2. Experimental assembly layout

The control system has three operating modes: HEAT STORAGE/FREE HEATING, ELECTRIC HEATING and SYSTEM OFF. If the system is stopped, before the sunrise the air inside the water-flow test box is cold. When the sun rises up, the air inside the test box becomes warmer. At a certain time solar gains makes that the temperature of inside air (T_1) exceeds the pre-set higher comfort temperature limit (e.g. 23ºC), and the system goes to HEAT STORAGE/FREE HEATING MODE. Then the pump is activated and the solenoid valve is opened, so the stored water (which is cold) circulates across the water chamber. The cold water circulation has a twofold effect: on the one hand it absorbs a part of the incident solar radiation, and on the other hand it removes part of the heat from the inside air. The heat removed by the water is stored in form of heat water in the isolated water tank. The system operates in this mode until a certain time after the sunset, when the internal temperature goes between the higher and lower comfort temperature limits (e.g. 21ºC and 23ºC) and the control system changes to SYSTEM OFF MODE. In OFF MODE the pump is turned off and the solenoid valve is closed, thus there is not water circulation. Later on, since there is no solar radiation, the temperature goes down below the lower comfort temperature. At this moment, two operation modes are available: if stored water temperature (T_2) is higher than the lowercomfort temperature limit(e.g. 21ºC) the system activates the HEAT STORAGE / FREE HEATING MODE. In this mode the stored hot water flow across the water chamber and releases a part of the stored heat. On the contrary, if stored water temperature (T_2) is lower than the lower temperature limitbut still higher than the external temperature (T_3), the system activates ELECTRIC HEATING MODE. Under this mode the electric heater and the pump are turned on and thesolenoid valve is opened. The system will work within this mode until the sunrise, when inside temperature will exceed the lower comfort temperature limit again. Since in ELECTRIC HEATING MODE, which may be activated along all the night,the flowing water is supposed to be warmer than external air, the energy consumption of water-flow window test box will be lower than the reference box, which only has two operation modes:ELECTRIC HEATING MODE and OFF MODE.

4 HOME AUTOMATION CONTROLLER

The described working scheme needs to be controlled by the home automation control system, which is able to register temperature dataand consequently acts over the pump and the electro valve. This control system consists of the following parts:

- Microcontroller board: An ArduinoMEGA ADK (Android Development Kit) equipped with an ATMega2560 microcontroller has been used. This board works with a 16 Mhz clock and has 256 KB offlash memory,54 digital I/O (of which 15 provide PWM output) and 16 analog inputs. Additionally this ADK version owns USB host capabilities, which makes that the board can establish a connection with an Android device(Arduino, 2013).This board manages all the systems partsand can be programmed with the desired control algorithm from a PC by means of an USB port.All the other boards must be connected to it, since it controls the whole system.
- SD logger shield: this board saves the experimental data in a SD memory card. So,the gaineddata that can be analysed later. It includes a RTC chip (Real Time Clock) to get data time stamp, andusesI^{2}C (Inter Integrated Circuit) busto communicate with the microcontroller board.
- Relay shield: itacts as a switch for every actuator or final control element,receiving the orders from the microcontroller. It is used for pump activation and electro-valve opening and closing actions. It works according to the microcontroller board orders.
- LCD display: a 16x2 LCD display is used to show information about the operating mode, the monitoring temperatures and other system parameters.
- Temperature sensors: Dallas DS18B20+ digital temperature sensors are used. These sensors have a 0,125 ºC precision, and make use of the OneWire communication protocol, which is able to manageseveraltemperature sensors using only one digital pin of the Arduino Board.A wiring diagram which includes all the electronic parts assembly is shown inFigure 3,while a picture of the real prototype can be seen in Figure 4.

It is interesting to note that the cost of the all the electronic parts and wiring was below 200 €.

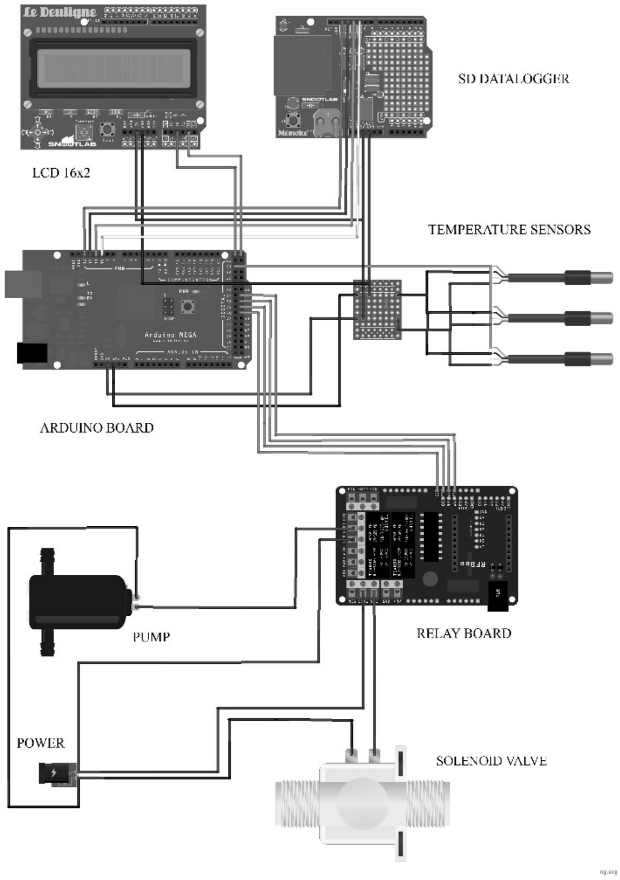

Figure 3.Basic prototype wiring diagram

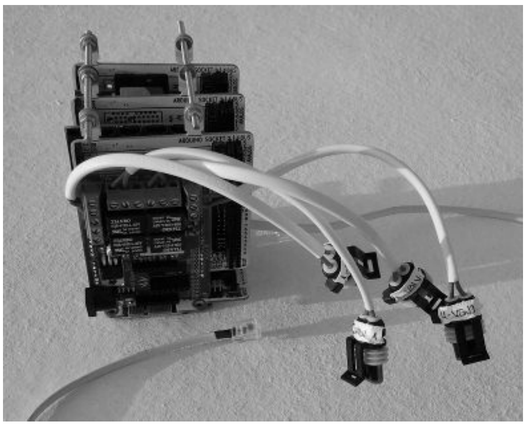

Figure 4. Control system prototype

5 RESULTS DISCUSSION

The developed control system is able to get relevant information regarding temperatures from the test boxes, to analyse it, to store it and according to it, to take control decisions in real time.

The temperatures along a winter day and night in Madrid are depicted inFigure 5. During the daylight time the water-flow window test box reaches lower temperatures than the reference test box due to the water circulation effect. As explained before, a part of the energy absorbed by the circulating water is stored in the water tank as*warm water*. Because of that, can be observed that at 20:00 h the water tank temperature is around 18ºC while ambient temperature is below 10ºC(Figure 5). At night, internal temperaturesofboth test boxesremainat 21ºC by the action of the home automation control system over the electric heaters. On the other hand, water tank and ambient temperatures decrease until the sunrise.

Stored water at 18ºC allows significant energy savingsat night, when it circulates through the water-flow window, lowering internal heat losses due to lower inside-outside temperature difference which consequently results in a heating demand reduction.The automatic control system helps to optimise the whole cycle by switching from pre-heating water at daylight hours (HEAT STORAGE MODE), to store it until it is needed, and finally to re-circulate it at night (FREE HEATING and ELECTRING HEATING MODE)when external temperatures drop down, in an adaptive and flexible seamless process driven by real time sensors information.

For a typical winter day in Madrid, the water-flow window test box, controlled by the home automation control system,offers a reduction of 28% of the heating energy requiredat night when compared with the reference test box, as can be seeninFigure 6.

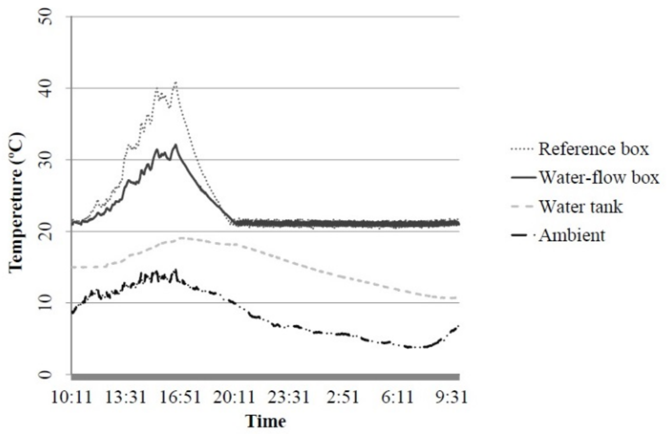

Figure 5. Winter day and night temperatures

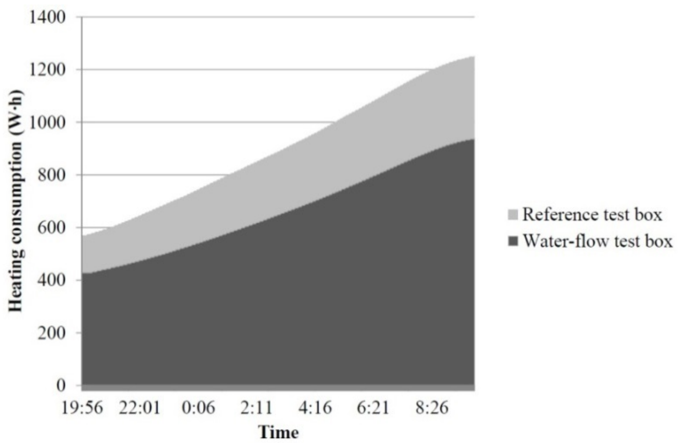

Figure 6.Winter night energy consumption

Regarding the use of the home automation control system prototype, it is interesting to note that networking capabilities can be easily added to it. Thus, it could be connected to a commercial home automation system by means of a LAN ora 3G/4G modem shield, and controlled from internet or any internal local areanetwork. Moreover, owing to ADK board characteristics, the system could be managed by any compatible Android device when properly programmed.

6 CONCLUSIONS

A new home automation controller for a water-flow window, based on the inexpensive Arduino open hardware prototyping platform, has been designed and built from scratch. The described system has been tested in a test box equipped with a water-flow based window that reduces in 28% the heating energy consumption for a winter night in Madrid. It owns continuously monitoring and managing capacities, so it is possible to optimize the energy efficiency of the facility taking advantage of solar energy with a certain delay of time, and without any manual operations.

The described system allows taking advantage of the high specific heat value of water, using the water flow window in winter season as a solar collector at daylight hours, and as an additional heating device at night hours, thus reducing energy requirements for heating and contributing to sustainability of buildings.

Due to its programmable characteristics several control strategies could beevaluated bywriting the corresponding programming code. The use of the ADK version of the Arduinoboard enables the system to be controlled from any Android device. On the other hand, by adding an Arduino compatible network interface (LAN/3Gmodem) the system could be controlled through a LAN or WAN network. Finally, it is worth mentioning that the total cost of the proposed home automation control system is below 200 €.

ACKNOLEDGEMENTS

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Concept and International State of Building Commissioning Activities

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ABSTRACT: The correction needs of energy and non-energy inefficiencies, improve new procedures and approaches skills to the sustainable management of buildings. Building Commissioning, a project management quality-oriented process, is internationally referred as one of the most profitable investments in the buildings performance. This work aims to describe the basics and provide an overview of the international state of such activity. Also refer certain matters related to the costs and benefits of the procedure.

1 INTRODUCTION

Most construction projects not satisfies his precepts of quality, costs and time. In the European Union, are referred wastes between 10 and 18% in construction (Brito & Sequeira, 2005), spent to eliminate errors due to lack of quality, expressed through the phases of Construction and Occupancy & Operation. Several studies indicate that are the upstream errors those of the highest impact.

Despite the high investment they represent, there are disparities in the intended building's performance. The combinations progressively more vast and complex of possible solutions, resulting from technological development and globalization of the construction industry in recent years, seem to worsen this negative trend. The construction industry is heavily dictated by the market laws, prevailing the power of initial investment's lower costs, such as by complicated and tangled responsibilities of the construction actors, to result in buildings with short and dysfunctional lifecycles, as well as in the dispersion of dynamic forces that should be promoted for common goals.

Furthermore, in the current scenario of energy efficiency as a top priority for the European Union, it is urgent to realize the potential for energy savings estimated for buildings. The residential and non-residential buildings are the main sector in energy consumption in Europe with 40%.

These issues challenge new approaches and processes. Building Commissioning (BCx) is one of them.

2 BUILDING COMMISSIONING

2.1 *What is it?*

BCx is inspired in the ship commissioning act used by the US Navy, since 1797, in the moment of placing a warship and his crew in active service. These means the verification and validation of the objectives and criteria labeled for the vessel in stages, since its conception, baptism, construction, installation of equipment and systems, ammunition, hiring and training of the crew, until his evaluation in open waters. Features and skills of the ship are considered valid, and the ship ready to be designated commissioned, if it is used by his own crew in an integrated relationship with efficiency (Department of the Navy - Naval Historical Centre, 2001).

The Cx application in buildings has also roots on the upstream quality concepts first introduced by Edwards Deming in the 1950s, and his Plan-Do-Check-Act cycle.

BCx means an integrated and proactive management process to ensure the project building requirements in all his areas and phases. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines the Commissioning Process as “a quality-focused process for enhancing the delivery of a project”, centered “upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements” (ASHRAE, Inc., 2005); for the CanmetENERGY it “is an intensive quality assurance process that begins during the design of a new building and continues through construction, occupancy, and operation. Cx ensures that the new building operates as the owner initially intended and that building staff are prepared to operate and maintain its systems and equipment” (CanmetENERGY, 2008).

It is transversal to various stages of the building projects lifecycle in all categories and differentiate into 4 types:

- Initial Commissioning (I-Cx) begins in the design phase of a new building and ends during Operations & Maintenance (O&M);
- Ongoing commissioning (OCx) is the extension of the Cx during the O&M phase, to the maintenance and continuous checking of the building requirements;
- Retrocomissioning (RCx) means the first implementation of the process in an existing building Cx;
- Re-commissioning (R-Cx) is a sort of Cx applied on buildings where it happened I-Cx or RCx. It is implemented to check, optimize and document the performance of the building systems. R-Cx can be developed as part of the OCx, or triggered by project modifications or O&M problems, for example:

Production	Pré-Design	Program			
		Planning	I-Cx	I-Cx	Missing ICx (or ICx documentation)
	Design	Preliminary Design			
		Working Design			
	Elaboration	Elaboration			
	Construction	Construction			
		Acceptance			
O&M	Occupancy & Operation	Post-Acceptance			
		Ordinary Operation	OCx	R-Cx	RCx

Figure 1. Types of Building Commissioning (International Energy Agency, 2010).

Through the project phase, as shown in Figure 1, the BCx process has specific activities. There are several manuals, prepared by many organizations, with specifications on the operation mode appropriated for each application context. Figure 2 presents, as an example, the Cx model from the "California Commissioning Guide," with a general description of the tasks of BCx.

Concept Design Phase	Design Phase	Construction Phase	O&M
The concept design phase is critical for the success of the whole Cx process as it defines the *Owner’s Project Requirements* (OPR) that will guide the design, construction, and operations of the future building.	In the design phase, the project evolves from concept to plan, drawings and specifications. The Cx activities ensure that as the building becomes reality, its systems and operations reflect the OPR.	During the construction phase, numerous aspects of the project are monitored and implemented to ensure that building systems and equipment are installed and tested according to the OPR.	The initial occupancy and operations phase is essential to close successfully the Cx process and to ensure that the expected benefits will persist beyond the typical one-year warranty period.

Figure 2. Cx Process overview (CanmetENERGY, 2010).

The BCx concept is relatively recent. In 1960, the Chartered Institution of Building Services Engineers (CIBSE), published the first Cx manual, dedicated to air distribution systems and, subsequently, to other equipment. It has formed the basis of the work performed and similar processes in other countries, such as Canada and Hong Kong. Cooperation between partners, motivated by the common needs of the buildings performance optimization, have accelerated the knowledge and the BCx process adoption globally, as shown in the next chapter.

3 STATE OF ART REVIEW

3.1 *International State of Art*

The International Energy Agency (IEA) is one of the main collaboration platforms in BCx.

Through the Energy Conservation in Buildings and Community Systems (ECBS) program, they executed two projects in the 90s, to develop Fault Detection and Diagnosis (FDD) tools, whose application in buildings of several countries converged on the same conclusion: “Most of these buildings have never worked properly!”. This launched them towards Cx as a way to avoid initial buildings deficiencies. Encouraged by the results of two international "workshops" arranged on the topic in 2000, they moved into a new project named "Anex 40", in an attempt to develop, validate and document Cx tools for residential and non-residential buildings, focused on Heating, Ventilation and Air-Conditioning (HVAC) and their impact on comfort and energy consumption (Internacional Energy Agency, 2004).

In 2005, the IEA proceeded with the completion of "Anex 47" involving 15 countries participation: Germany, Belgium, Canada, China, USA, Finland, France, Hong Kong, Hungary, the Netherlands, Japan, Norway and the Czech Republic. The main purposes of this program was the Cx application in new or existing buildings for improved performance in O&M. Methodologies and techniques have been developed in the purpose of automating the "intuitive approach currently applied in the buildings operation", focused on relevant energy savings. 4 publications resulted from these projects:

- The "Anex 47 Report 1: Commissioning Overview", which gives an introduction to the Cx process;
- The "Anex 47 Report 2: Commissioning Tools for Existing and Low Energy Buildings", which contained general information about the application of Cx tools in low energy and existing buildings, including a summary of specifications for the tools developed in the program and the presentation of case studies;
- The "Anex 47 Report 3: Commissioning Cost-Benefit and Persistence of Savings", with the presentation of information collected to promote BCx and the methods for the determination of costs and benefits of the process. The report also gives emphasis to the differences in the Cx definition between countries;
- The "Anex 47 Report 4: Flow Charts and Data Models for Initial Commissioning of Advanced and Low Energy Building Systems”, with the state of the art review of the use of flowcharts and models in the practice and research of I-Cx in advanced and low energy building systems (International Energy Agency, 2010).

The research under these IEA ("Anex" 40 and 47) projects established the basis for development of Cx manuals in several countries and are, actually, the main forum for BCx knowledge and his international expansion:

- Asia:

The People's Republic of China is the largest global energy consumer, with the construction sector representing more than a third of the total. Annually constructs 2 billion square meters of buildings, with a growing urbanization process. The energy consumption of 80% of these buildings are considered high and their efficiency levels are below those seen in other countries. It is expected that 60% of the Chinese population will inhabit urban areas in 2030 (up from 45% in 2006). The World Bank projects that by 2015, half of all new worldwide buildings will take place in China (Chmutina, 2010).

In this scenario, the Chinese government consider fundamental the construction of Green Buildings in the energy consumption and carbon emissions reducing pursuit for the respective 16% and 17% per unit of GDP, marked for 2015 (U.S.-China Economic & Security, 2011).

A Green Building evaluation system, called Green Olympic Building Assessment System (Gobas), supported by the Ministry of Chinese Science and Technology, was implemented in 2003 in an attempt to correct the bad practices of sustainability applied to building projects until then, and to compliment de slogan “Green Olympic”, made the world to achieve the Beijing Olympics in 2008 (Lin, Ouyang, Gu, & Tian, 2005).

The Gobas system is similar to the Cx process, a rating system scaled by stages, in which the aspects related to energy consumption and building performance are the features most valued.

The University of Thingua has actively participated in Gobas and collaborated with the government of China, including the development and implementation of "Designer's Simulation Toolkit" (DeST) software, for the HVAC design, under the slogan "design by analysis, design for simulation". The design is performed according to the phases indicated in Figure 3.

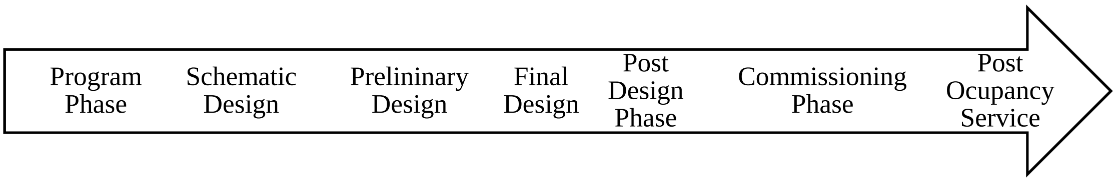


Figure 3. Gobas HVAC Design phases (Nakahara & Shimazu, 2007).

The same university has collaborated with the Ministry of Governmental Affairs of his country in the Cx application, both as RCx over 20 government buildings, as buildings projects executed for the Olympic Games in the summer of 2008, held in Beijing (Nakahara & Shimazu, 2007).

Moreover, it is known without details, that the Chinese Ministry of Construction published, in 2008, acceptance codes for building services equipment and building systems. The entities involved expects a growth of BCx activity in the country (International Energy Agency, 2010).

Hong Kong, a Special Administrative Region of China, has a massive curriculum and activities developed in BCx, because of its historic links with the UK and natural contact to his pioneering Cx model In the 90s, the Hong Kong government has published 12 collections of Cx procedures, based on the CIBSE manuals, designed for operation in public buildings. However, these specifications have been widely accepted as a reference model and applied by the construction sector in private buildings (International Energy Agency, 2010).

– Europe:

The European Commission has motivated many countries to consider BCx in their strategies, by the Concerted Action - Energy Performance of Buildings Directive. The Directive 2002/91/EC, revised the May 19, 2010 (2010/31/EU), triggered the discussion and implementation of energy efficiency in buildings by prescribing a set of targeted measures on the Kyoto protocol goals and on the reduction global emissions of greenhouse gases compliance. For this promotion on the energy buildings performance were established, among others, the following requirements:

- Energy certification for buildings or building units;
- Regular inspection of heating and air-conditioning systems in buildings; and
- Independent control systems for energy performance certificates and inspection reports.

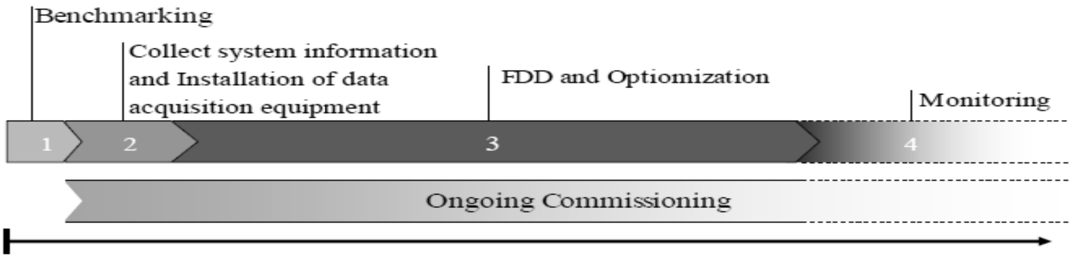
Despite the aforesaid requirements corroborate the principles of Cx, its implementation by the member states is ineffective. With rare exceptions, there are no specifications, manuals or tools to support a BCx systematic process. Belgium, Czech Republic, France, Netherlands, Norway and Switzerland are countries whose activities are located mainly in the Research and Development phase. UK, Germany and Finland have particular histories.

The UK is a pioneer in Cx applied to buildings, originally characterized by a fragmented approach and focused on the construction final stages. Then, by the early 1990s, the activities of BCx independent until then, became a subcontractor role in order to increase competitiveness in a market increasingly disputed. Currently, this activity is carried out as an integrated process and commonly used since the design phase of high dimension projects.

Germany law rule, since 1976, teams design for a set of tasks very usual in the BCx activity, such as the supervising performance tests and statement of deficiencies prior to post-acceptance phase, or even, from this moment, supervising the rectification of deficiencies that fall under the warranty periods of the building (two years for the contractor and five for themselves).

Currently, this country's Federal Ministry of Economics and Technology develops the research program dedicated to energy optimization in buildings, called EnOB. More than twenty of these demonstration buildings are referred that "surpassed national energy consumption standards by 50 % without incurring additional building costs". This EnOB program supports several projects related to Cx. ModBen is another German relevant project. This "top-down" approach, deals with the development of processes and tools to identify potential energy consumption reductions during the operation of existing non-residential buildings, in a simple and economical manner, by FDD and continuous performance evaluation. The ModBen process is represented in Figure 4.

After showing that new materials and systems can facilitate energy buildings efficiency, the EnOB program continues with the ultimate goal of creating new technologies and integrated buildings concepts of and their energy systems. They have reported good results (EnOB: Research for Energy Optimized Building).



Legend:

	Step 1	Step 2	Step 3	Step 4
Name	Simple Benchmark	Certification	FDD + Optimization	Regular Inspection
Description	Gather basic consumption and stock data and first classification / baseline of the building performance.	Certification according to national implementation of the EPBD.	Analysis of the building performance, identification and implementation of energy saving measures and optimization of performance	Maintain optimized performance by ongoing (minimal) monitoring

Figure 4. ModBen step procedure (International Energy Agency, 2010).

In Finland, the contractors had adopted BCx related tasks as a quality assurance of their services, especially in the final stage of building construction. In early 2003, it was launched the "Tova" project (the Finnish BCx designation) under the Finnish programs "CUBE - Building Services" and IEA (Anex 40 and 47). Inspired by the procedures used in the U.S.A., the BCx concept has been worked to an application since the stage of design, with a clear definition of the project requirements, until the monitoring of whole buildings life cycle, including as part of the activities of Facility Management. In 2007, the Finnish research center VTT, published the "Tova" manual, with a general description of the BCx. In a recent article (Pietiläinen, *et al.*), it is written the need to perform an increasing number of pilot projects in order to assess the practical potential benefits estimate for the country.

– North America:

According to Anex 47, the introducing of BCx in North America happened in the Canada province of British Columbia in 1986, through the Cx manual publication dedicated to buildings mechanical systems. Contrary, the Portland Energy Conservation, Inc. (PECI) refers that all begins in 1977, with the projects developed by the Department of Public Works of Canada and, after four years, in the design, construction and start-up of Walt Disney's Expo Center. The difference versions may be understood by the explanation given by the General Services Administration (GSA) (U.S. General Services Administration, 2005), for whom the concept of BCx is historically associated with the process of test and balance of HVAC equipment, an approach which excludes other systems that do not directly affect their performance.

More peaceful is the information that the 90's represents the emergence of BCx industry in Canada and U.S.A., with a similar story to the other countries: the decree of the energy efficiency needs, improves the ingenuity of BCx. In this case, to the goals established for the efficiency of every new public building project in 1992 by the Department of Energy (DOE) as part of its policy of energy conservation, corresponded efforts with innovative and public domain results: in the following year, the GSA develops the Building Commissioning Guide, clearly suggesting the integration of the Cx concept to all the features of a building, even applying the term Total Building Commissioning (meanwhile, ASHRAE published the "Guideline Commissioning HVAC"); in 1994, the President Bill Clinton signed an executive order implementing the BCx process to all federal buildings. Similar results and chronology occurred in Canada, with the publication of the "Project Commissioning Manual", by the Department of Public Works of Canada.

Since then, both governments have used BCx as an important strategic tool and encouraged its expansion and application.

In the U.S.A., the DOE sponsored a national development program and in that same year of 1998, the United States Green Building Council included the Cx application as a requirement for LEED certification, which is an important milestone in the progress of the activity. A lot of information was published and many conferences held from that time until 2004. The BCx activity in the U.S.A. has deeply increased in recent years, with a growing number of companies providing this service and technicians performing qualification and accreditation in the area.

The ASRHAE, the PECI, the California Commissioning Collaborative and the Building Commissioning Association are organizations involved in this BCx promotion, also internationally. The manual entitled "ASHRAE/NIBS Guideline 0-2005: The Commissioning Process" is considered one of the most instructive documents for the Cx application process and is a reference for many organizations and countries.

3.2 *Costs and Benefits*

One of the restrictions identified to BCx penetration in the international construction market is the lack of knowledge on the costs and benefits of its application in building project. The Cx community recognizes it, saying that "it remains an enigmatic practice whose visibility severely lags its potential" (Mills, Building Commissioning - A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions, 2009).

Thus, the efficiency of the BCx investment itself is a subject often treated in the literature about the theme.

In 2009, Lawrence Berkeley National Laboratory published a study in the U.S.A., in which are summarized and analyzed real data collected from Cx projects conducted in 634 buildings in 26 states. The following results are reported:

- Average Cx cost: \$ 0.30 and \$ 1.16 per square meter of existing and new buildings, respectively, 0.4% of the total cost of new buildings construction;
- Average energy savings: 16% in existing buildings and 13% in new buildings;
- Payback time: 1.1 years in existing buildings and 4.2 years in new buildings;
- Projects with a comprehensive approach to commissioning attained nearly twice the overall median level of savings and five-times the savings of the least-thorough projects;
- There are many non-energy benefits that often compensates the cost of the whole Cx process;
- There is an energy savings potential estimated at 30 billion dollars in the U.S.A. market until 2030 and 340 megatons annual reductions of CO2. A Cx industry designed to achieve these benefits would imply an annual sales volume of 4 billion dollars and 24,000 post jobs.

A study about the Cx application in 55 buildings by the same American laboratory, determined the structure of BCx cost represented in Figure 5.

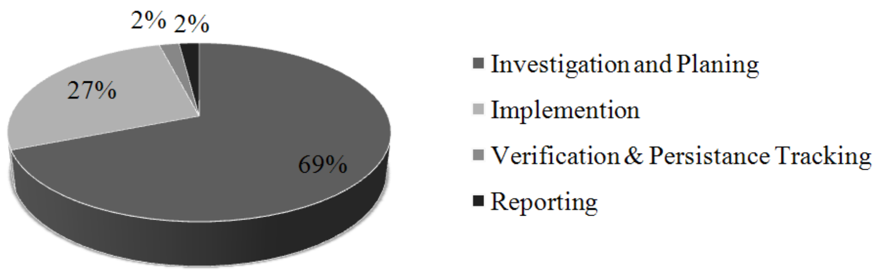


Figure 5. Commissioning Cost Allocation (Mills *et al.*, 2004).

BCx costs are variable depending on the nature, building size, complexity, age and condition of the equipment and systems, as well as the staff knowledge and the existence of adequate documentation. The BCx price is commonly presented as a series of potential costs because there aren't standardized conventions and they are difficult to determine. The non-energy benefits resulted from the BCx application, are distributed as shown in Figure 6.

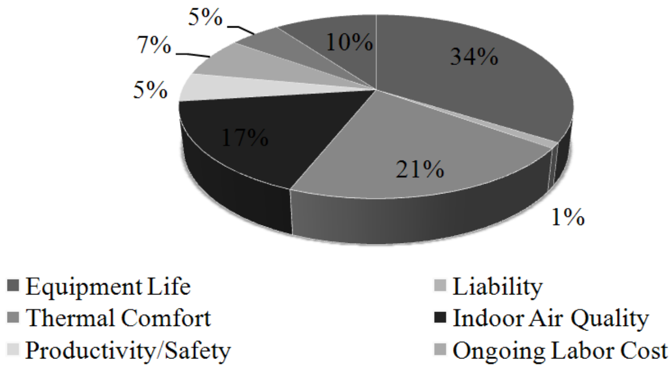


Figure 6. Reported Non-Energy Impacts (Existing Buildings) (Mills *et al.*, 2004)**.**

4 CONCLUSIONS

The BCx activity has increased in recent years in countries that have established purposes of environmental and energy consumption. It is the national governments that encourage the implementation and development of BCx through various actions. Since specific legislation, through collaborative research with universities and even giving the example of the concept integration in its own buildings, there are several real cases that demonstrate BCx as a strategic tool of public interest in sustainable management achieving. In this context, the Cx application to Building Enclosure, adapted to Portugal, is being worked at University of Minho. It is expected to kick-off the subject by the elaboration and development of Manuals and Tools.

By recent publications and methodologies assumed, the international collaborations have achieved positive results, with the import and adaptation of best practices documented in different regions.

The reported benefits are interesting. Apart from the environmental advantages that the BCx application means, immediately checked by energy savings in several case studies, the calculated payback time, smaller in new buildings, and the estimated impact for the American market, suggest important economic advantages. Also the functional component is relevant, as is deduced from the non-energy impacts reported that often compensate the total BCx cost, and from the nature of the main benefits obtained, such as extending the life of equipment, the indoor air quality and thermal comfort.

The BCx cost structure indicate that are the Research and Planning activities that consume most of the funding, with 69% of the total, which suggests as critical all the tasks required for testing, monitoring and diagnosis.

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Sustainability in Danish Social Housing - The User Focus

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ABSTRACT: The idea with this multiple case study is to investigate the relation between man, sustainability and architecture. The focus is directed on the user dimension, behaviour and sustainable housing. A triangle can be set up between Architecture, Sustainability and the relationship to the User. Subsequently the project will have the interest of the mutual relations. How does the user relate to the architecture and sustainability, how is everyday life of the end-user in relation to architecture and at last, how do the user validate sustainability. The research should contribute to architects, so new knowledge can be used in upcoming architect design processes.

1 INTRODUCTION

1.1 *Ongoing PhD-research*

This ongoing PhD research project will attempt to illustrate the relation between architecture, sustainability and the relationship with users. The project focuses on sustainable social housing located in Denmark. A research project, in which multiple case studies and by interviews with different user group's experience of decision-making, living and using sustainable housing. A study of the everyday practices and valuation of the various users. How is the communication of information regarding the servicing of buildings? How is information for the end-users? Is there an understanding of all user groups around the sustainable initiatives?

This research project is interesting also to examine how resident's democracy works in relation to political decisions about sustainable approaches in settlements. Residents' democracy can reject the architect's proposal of new sustainable approach. What can we do to look more broadly at a sustainable solution?

This PhD project is also interested in the general principles of the learning and experience process between the different partners in a sustainable housing project. From the architect to manager department in the social housing association. From the facility manager department to the operation staff. Then from the operation staff to the end-user and back again to the architect. How is sustainable knowledge and experiences disseminated and taught in the specific buildings? What general lessons can be derived across all cases? In regards to the learning of the development of competence that must be done from the architect to the users. There will be addressed questions to the user groups with regard to the future. What experiences users have had with the homes they live in? Experience, as the architects can have a direct benefit in organizing future design processes.

This research project thesis is that if serving the users in the operational phase and end-users everyday practice does not take place with expected learning and appropriate behaviour in relation to the architects' intentions behind the sustainable initiatives; there can be raised questions about how sustainable public housing is. In addition, if a resident democracy are opposed to sustainable solutions, how do the social housing association's future-proof their settlements?

The project's research question is: "Why are administrative users, operation staff, and residents relevant in relation to sustainability in Danish social housing, what will encourage and impede sustainability, and how can users narrative about their everyday life contribute with new knowledge to architects?"

The hypothesis is that if the administrative users, operations staff, and residents of Danish general housing does not have the expected consumption behavior, knowledge of, learning about, and handling of a positive valuation of the sustainable approach the architect has incorporated in its architecture, so I expect that it will be a barrier and have a negative impact in relation to the expectations for sustainability. There will be directed after qualitative empirics, which can confirm or deny the hypothesis, on the other hand, by recover specific knowledge of each settlement and derive general features across all the selected settlements.

Inspired by Elizabeth Shove's research (Shove, Watson, Hand and Ingram, 2007) on consumption among users, you can draw a triangle showing the three main points – the user (man), sustainability (theme), and architecture (artefact).

The user, the sustainability, the architect, the architecture and the everyday life is linked to ethical, political and an ideology dimension (value). So if the user has a specific position on sustainability, how will this position be true? Everyday life dealing with consumption patterns in which also the economic dimension is applicable. What everyday practice, does the user have in relation to the architecture in which he or she lives?

The research project is inspired by a multiple case study of recent sustainable building in Denmark, made by the Danish Building Research Institute at Aalborg University and the Technical University of Denmark (Jensen, Joergensen, Lauridsen, Quitzau, Clemmentsen and Elle, 2010). The study reached the following conclusion as the authors writes: "When the building project indirectly implies that residents are not very ecologically minded, this also leads to the houses not asking too much of users; residents should live a "normal" life in the houses without having to show a particular interest in environmental technology and sustainable lifestyles. The question is whether this function smoothly, and if not, what types of problems it entails and how to address them".

In addition, the following statements from the same multiple case study in relation to the use and operation of housing: "With sustainable houses having a different design than ordinary construction; it involves these tenants having a different use of the property in relation to heating, ventilation, etc. In relation to this, it can be problematic if the residents are not aware of the functionality of the property. Therefore it can be a potential problem when the target group is so-called 'ordinary citizens' who do not necessarily have the required knowledge of any special conditions in a sustainable building. Choice of ordinary citizens as target implies a need to inform the residents, so that they can develop the expected use of the property" (Jensen, Joergensen, Lauridsen, Quitzau, Clemmentsen and Elle, 2010).

2 USER GROPUS

2.1 *User group 1*

The central administrative facilities management departments handle the overall administration of the separate estates. The facilities management departments typically consist of employees with a large amount of construction expertise to ensure professional handling of technical building installations. The staffs are typical architect, engineer, installation engineer, energy consultants, etc. These technical administrative users undertake communication and dissemination of sustainable knowledge to the operation staff. A larger public housing associations usually have these types of professionals employed as an internal building consultancy. Not all social housing associations have this kind of building expertise in-house. They will typically enter into a business arrangement with a larger general housing unit of consulting firms.

2.2 *User group 2*

It is assumed that the operation staff can and will grasp the housing development's sustainable knowledge. It will be crucial that the operation staff have the necessary skills to serve users during the operational phase. If these skills are not present, it will be necessary to enhance skills. Many adults already in work are not necessarily interested in acquiring new learning. In particular, early school leavers have a certain reluctance "to go back to school" (Illeris, 2009).

The second aspect is whether the decentralized operation staff will. One must assume then that the key operation staff are interested in working professionally with the building operation. Alternatively, a personal valuation of the sustainability theme could affect the servicing during the operational phase. Both in the positive and negative sense, depending on the individual's values. This project will examine this user group's position on the concept of sustainability and its impact on everyday practice.

2.3 *User group 3*

This group is the so-called ordinary people living in dwellings - called end-users. They have as a starting point, not the necessary technical knowledge on sustainable construction. End-users will be depend on getting information, learning and skills to have the desired behaviour for the sustainable construction works. This must happen through the administrative and the operation staff. In the end-user group there is politically elected board members called tenants board, which is covered by the Danish law on social housing. The tenants board, has the right to accept or reject ideas and proposals which relate to the settlement. For example, it may be proposals from a sustainable renovation of a building that will affect any possible rent increase to building improvements and increased costs for the operation. This project will examine the position of the tenants board on the concept of sustainability and its impact on everyday practice.

3 THE USERS AND SUSTAINABILITY

3.1 *Sustainability and the users*

In our time, is sustainability the prevailing paradigm? The technology leading the way takes its starting point in sustainability. Sustainability, Technology and lifestyle are closely related (Gram-Hanssen, 2012). Good sustainable design can be simple and is perhaps the best option when you consider that it is ordinary people with no special skills who shall live in it. By following the process of the creation of buildings and throughout the operational phase, it will help us to understand the users. You will understand what kind of sustainable initiatives work and which ones should be improved. It is equally important to understand the users’ everyday practices around energy. "The users are just as important as technology" (Bennetts and Bordass, 2007).

Technological objects ultimately release time from operational tasks in the home and give us time for other purposes. When we will buy a new kitchen we construct a new lifestyle and so construct a new everyday practice. You could say that people are reflected in the things they own (Shove, Watson, Hand and Ingram, 2007). It might also be said that when we provide new sustainable housing designs we perhaps also construct another new everyday practice?

Residents focus on the costs and rarely on the saving. If you ask the general administrative in the social housing associations in Denmark, they respond that end-users either demand or have interest in environmental efforts. End-users are interested in a cheap administration. Sustainability initiatives in building operation do increase the administrative costs. There is a dilemma, as an operation department on the one hand, is responsible for the operation and on the other hand the end-users' economic resentment. Environmentally controlled building operation is all about hard technical knowledge and understanding of the residents housing culture and lifestyle - if one of these is missing, it would be difficult to implement (Jensen, Jensen, Elle, Hoffmann, Nielsen and Quitzau, 2008).

3.2 *End-users participation from planning phases to operational phase*

European Directives describe the decision-making processes concerning historic buildings and efficient energy including a report for Public hearing. The UNECE Convention (The Aarhus Convention) on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, recognizes that people have the right to take part in basic decisions affecting their lives. It recognizes that the quality of these decisions can be improved through the active involvement of public concerned (UNECE, 1998). The Charter of European Cities & Towns Towards Sustainability (The Aalborg Charter) I.13 says: "We, cities and towns pledge to meet the mandate given by Agenda 21, the key document approved at the Early Summit in Rio de Janeiro, to work all sectors of our communities - citizens, businesses, interest groups - when developing our Local Agenda 21 plans" (ESCTC, 1998). In the Aalborg Commitments concerning Planning and Design tell about, that there will be work to apply the requirements for sustainable design and construction, and promote high architecture and building technologies (ESCTC, 2004).

The most recent renewals are also on the operating side, where the housing association leaves the primary management of operation and maintenance to the residents. The caretaker's function is committed and the intention of social housing association is, that the residents themselves must take ownership for the maintenance of their common buildings, common areas and common usage. Again one can ask the question whether end-users can and will contribute to the individual housing profitability? If there is no economic incentive for the end-users, is a barrier to the environment-controlled building operation (Jensen, Jensen, Elle, Hoffmann, Nielsen and Quitzau, 2008). What is the motivation and driving force for the end-user?

When end-users are not directly involved in the development of the homes there might be a risk that the residents do not even take ownership of the building. The latest renewals to counteract any possible opposition from the residents' are that the social housing association leaves the running and maintenance of the buildings to the residents. In other words, the caretaker function is removed. This PhD project examines a case where end-users themselves are responsible for the running and maintenance.

3.3 *Sustainability and the end-user*

The administration of the social housing association must ensure the learning of embedded sustainable initiatives in the settlements. The sustainable intentions of the architect, is subsequently transferred to the end-users. It is creating a joint ownership (Jensen, Joergensen, Elle and Lauridsen, 2012). The facilities management department does have an information and education commitment regarding the relevant knowledge about the use of sustainable technology to end-users. When the architect and the rest of the consultant team, in collaboration with the construction company, has transferred its completed project to the housing association tenants, it is ready for occupancy. For the development's calculated operating accounts to be met, it will often require that end-users should act in a particular manner in relation to electricity, water and heat. The consultancy team has in the project planning phase allegedly stipulated an overall repayment period of construction costs for the sustainable initiatives.

Typically, the communication and learning of this knowledge are given to the end-user through the delivery of printed resident information. From then on it is up to the individual residents themselves to familiarize themselves with the material and create their own understanding. This could be possibly followed up with special information sessions for residents. General housing associations have also started to communicate via their websites, supplemented with video giving information on procedures for the operation and maintenance of residential buildings. It is interesting to examine, whether these presentation variants are affecting end-users' everyday practice.

Does the appropriate learning happen? Is it a learnt behaviour that the residents also use in their everyday practice? While you are using network-based communication for self-learning, it will be essential that users have a considerable motivation and willingness to engage (Illeris, 2009).

This requires that end-users can and will take the required learning of the necessary sustainability initiatives and the consequent desirability of user behaviour. It is a requirement that the end-user will receive this more or less complex information. When there is a willingness to learn, it is because the end-users desire involvement, the acquisition of new knowledge may depend on personal valuations around the sustainability theme and habits, social activity, economy and consumption in everyday practice. There are "black holes" concerning advice to end-users (Jensen, Jensen, Elle, Hoffmann, Nielsen and Quitzau, 2008). This PhD project will examine whether the end-user can and will grasp the information. In a recent study of sustainable building in Denmark, the residents indicated that they were uncertain about the proper use of their property. As Jensen, Joergensen, Lauridsen, Quitzau, Clemmentsen and Elle (2010) writes, the end-users could be in doubt over ventilation and regulation of floor heating: "Should we open the window or the door to ventilate the bedroom? Do you destroy process by airing out? What does it mean that the appliance is running?"

"The residents' behaviour affects the function and consumption in each house. Whether it just depends on knowledge can be discussed as aspects of the cases indicate that there may also be a de-selection from the residents', in relation to comply with the environmental requirements outlined in the projects" (Jensen, Joergensen, Lauridsen, Quitzau, Clemmentsen and Elle, 2010).

3.4 *Sustainability from the administrative user to the operation staff*

Administrators emphasize the ongoing dialogue with the operating staff as very important for environmental performance. Organizing and anchorage is in general very closely connected to the building of resources and knowledge of environmental and resource conditions in a property. Further training of operating personnel is needed. Management refuses to even out the missing skills. In addition to the possible lack of knowledge of operating staff does not constitute a barrier to implementation of environment-controlled building operation. It is necessary to empower the caretaker better to engage in dialogue with the residents (Jensen, Jensen, Elle, Hoffmann, Nielsen and Quitzau, 2008).

3.5 *User behaviour and overall economy*

The relationship between the operating costs and the building construction are essential for the social housing associations. In this context it is interesting to examine the residents, caretakers and administrative operating everyday practice. Their everyday practice and attitude for universal sustainable buildings will have an impact on a profitable overall economy. The social housing associations must ensure a quality building at a reasonable cost, because they subsequently bear the additional operating and maintenance costs arising from any lack of quality.

In order to improve the quality of in the sector of the social housing association, the introduced a requirement for assessments of building the overall economy. By planning and project assessed the total construction costs relative to operating costs. In addition to the environmental and societal benefits, total economic assessments will be a key parameter in the municipalities own assessment of whether a construction project should be implemented.

Quality of construction is a parameter to be assessed and the second is the user's handling of the operation. Several environmental analyses examine energy consumption, water use and use of other natural resources, but not the experiences of maintenance (Shove, 2003).

The total economic considerations constitute a competitive advantage by public architectural competitions and tenders. The award criteria with total economy in focus mean that the bidders are forced to deal with the economic profitability throughout the Lifecycle of the building. The weighting of this ratio gets larger and larger influence on the winning projects. But if there is so much focus on the economic viability, it would also be interesting to investigate whether the user also has the same focus. The Ministry of Social Affairs earmarked in 2011 funding to projects planning energy savings in relation to the user behaviour and the overall economy (ESCO model).

This research project will follow a pilot project in partnership with housing association KAB and Energy Fund. In this study, the project establishes three new townhouses with separate energy measurement devices in individual homes. A reference building and two measuring buildings. The advisors involved will examine building's energy consumption and the individual end-user energy consumption. In addition, how consumption is broken down, by month, etc. The idea is also that the measurements must be collected and sent to the server and displayed in the display in each home.

Several parameters can be crucial for the sustainable initiatives now for making accommodation in general, and also social housing associations sustainable. There is a tendency that the larger the income a family has, the more consumption they will have. However, it is the single person living alone who puts a bomb under sustainability. Power consumption is greatest on average, with fewer people living in the dwelling. Consumption is influenced by residents 'learning habits and residents' comfort practices. The fact that you live with others is not necessarily sustainable (Gram-Hanssen 2012). Furthermore, the fact that there is an increased number of electronic devices in each home in Denmark should be considered (Gram-Hanssen 2013). The complexities of changes in practice seemingly in a way that moves by the established theories about consumption and technology (Shove, 2003).

3.6 *Visibility of sustainable iniatives for the user*

User motivation can be a value judgment, political or as a penalty or reward bracket (Thurén, 1994). The reward could be an economic incentive by reducing consumption. So that consumption in the home can be seen directly by residents - electricity, heat or water meters. Not just the meters located in the cupboards or under the sink, but the digital meters in a more "natural eye level" e.g. consumption could integrate on water fixtures with a direct visualization of consumption translated into costs. The rewards could also be at a visibility of consumption on the individual's behalf to supply firms. The penalty will of course be a larger bill if increased consumption. The Housing Association may assume that most end-users adjust their behaviour appropriately, but it would be interesting to identify if the users "adapt" their behaviour and consume appropriately.

There is also the aspect that deals with end-users receiving the necessary information. This requires specific skills and competencies; otherwise there is a risk that the housing association will not achieve the intended effect. The residents of public housing estates have different educational, cultural, linguistic and social backgrounds. This requires that the information be designed so that it meets these diverse criteria. A provision must be made that takes into account that it is from the non-skilled to highly educated people who should be able to understand the message. Also, it should be translated into the relevant languages which are spoken in buildings, etc. One can imagine that if the social housing associations administrative departments do not consider all these factors in the communication, then the messages may be received differently than expected.

4 RESEARCH METHODOLOGY

4.1 *Document analysis*

The architect’s documents regarding their ideas and thoughts about sustainable initiatives will be analyzed. This analysis is crucial to understand the purpose, as all user groups subsequently get diverted when they take over the project. So these architectural documents as descriptive text, analyses, drawings, illustrations, etc. are very important. They serve a purpose for the sender, and then they may have a function for the different receivers (Groat and Wang, 2002).

Other documents such as, operation and maintenance manuals and user manuals are intended to provide guidelines for users' actions. Therefore, this kind of document is also interesting to analyze and compare in relation to users' own experiences. Do they even have knowledge that these documents exist? Do they know the importance of these documents in relation to user behaviour and consumption?

The way the analysis of the collected documents is performed depends on the research question. Document analysis can as Brinkmann and Tanggard (2010) writes, “identify trends and patterns in the material - the stability and change - happens over time".

4.2 *Interviews*

The interview has become a common way to gain knowledge about people's lives, opinions, attitudes and experiences. Brinkmann and Tanggard (2010) describe it as follows: "Life world is the world we know and meet in everyday life”. By using the qualitative research method one achieves the narrative storytelling. The narrative research approach has been chosen because the individual stories must be told to get personal experience about how to ensure better interaction between user and sustainable housing. Narratives are interesting for scientists because they are assumed to guide and organize behaviour. Narratives are dynamic and therefore susceptible. Narratives are contextual or situational related. Only by changing his story about himself, can the subject change his behaviour. The collection of user stories will focus the spotlight on the uncultivated areas of user behaviour in social housing. The qualitative data will be used in user group’s forward-looking behaviour, but the lessons learnt can also be used for project architect’s upcoming designs of future social housing projects (Brinkmann and Tanggard, 2010; Groat and Wang, 2002).

The interviews will be conducted face-to-face and as a focus group in multiple case studies. The interviews will be conducted as semi-structured with a dictaphone as a tool used to record. The semi-structured interviews is conducted with an interview guide that ensures the conversation leads to the desired topics - everyday practice in relation to architecture and ethics in relation to sustainability. It is important that the interview appears openness to new unexpected phenomena - curious and responsive. The study of the “why” and “what” should be clarified before the “how” is reached (Kvale and Brinkmann, 2009).

All interviews will be transcribed and the written text and audio recording together constitute the material to be subject to the subsequent meaningful analysis. This PhD dissertation must be disseminated to the sector of the social housing association in Denmark, user groups and especially Danish architects and other consultants. It must therefore be a reader-friendly product and will be written in Danish, so all the Danish recipients will get the most out of the research. Research papers and conference presentations during the course will be in English and Danish.

A work journal will be kept as a record of the experience obtained during the study. Transcription will be carried out. A systematic analysis should provide an overview of a large transcribed text material. Narrative statements from the three user groups, from the specific housing projects will be grouped and analyzed (Groat and Wang, 2002).

4.3 *Photo documentation*

There will be carried out an ongoing photo documentation. There will be made by the current settlements, single buildings, sustainable solutions, process with the users, user meetings, focus group interviews. If there is a wish from the users, on the possible anonymity in the context of photo documenting, this will of course be respected. There will not be taken photos without users' consent.

5 CONCLUDING

The intentions of this PhD project is to create new knowledge about the interaction between the user, sustainability and social housing. There will be an open and flexible approach to the methodology for the number of participants who can be interviewed, the number of interviews and the number of the case which is currently selected. Users' narrative stories of this interaction will be collected through interviews. Data will be analyzed to provide new qualitative knowledge of each settlement, and a general knowledge across all of the cases. This general knowledge, offers a broader understanding of users' ambitions and competence in relation the importance of managing sustainable settlements. General knowledge will be for the use of the architects in the design of future sustainable housing. In addition, this knowledge contributes to the users and to the sector of the social housing association in Denmark .

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Tradition in Continuity: thermal monitoring in vernacular architecture of farmsteads from northeast Portuguese region of Trás-os-Montes

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ABSTRACT: The study focuses on the identification of a typology of vernacular architecture, characterized by dispersion and isolation on a territory usually associated with concentrated settlements. This paper aims to contribute for understanding how local factors (climate, economy, culture, etc.) influenced vernacular architecture inthe northeast of Portugal by analysing the strategies and building solutions that enable it to cope with climatic adversities. Through *in-situ*monitoring temperatures and relative humidity,is attemptedto show the potential of the case studies in maintaining the indoor air temperatures within the boundariesof comfort even when the externaltemperatures are outside the boundaries.

1 FRAMEWORK AND OBJECTIVES

This paper aims atidentifying and atcharacterizing a typology of vernacular architecture from thenorth-eastern region of Trás-os-Montes, understanding its integration in the territory, the management of local resources and its relation with the city. In the previouslystudied typologies in this region, usually associated to concentrated settlements,the street is the link between the house and the village. This study seeks the exceptional elements like farmsteads, dispersed on the territory. Thus, it is intended to (1) contribute to the knowledge and preservation of these, until now, unprotected architectures,characteristics of local culture and identity, through survey and registration, but also (2) to understand and scientifically validate vernacular solutions and strategies, contributing to the development of contemporary solutions.

The awareness that resources, but also the territory, are not unlimitedhave led to the emergence of new standards and regulationsapplied to buildings: the *Passivhaus* concept, proposing passive solutions that ensure minimum energy consumption for a house, or ZEB models (Zero Energy Buildings), buildings that over a year do not consume more energy than they produce. These trends are the most representative of the discussion in the field of energy efficient buildings, and areabove allbased on the Energy Performance of Buildings Directive(EPBD, 2010) that set that all new buildings must comply with the n-ZEB standard (nearly-zero energy buildings) by 2020.

By their isolation from theestablished infrastructural networks, the typology in study isan especially relevant case studyfor self-sufficient construction,i.e. for interventions that are aimed toreinterpret the integration of design strategies with cultural and geographic environments.These strategies remained viable for hundreds of years and are the result of an experimental evolution of ancient wisdom. It is precisely this character of continued evolution of the vernacular heritage, its flexibility and ability to be adapted to the climate and other environmental factors, that is the focus of this paper.

2 BACKGROUND ON VERNACULAR HERITAGE

Since the late 19th century several researches on vernacular architecture were conducted seeking for the autochthonous characters of the different nations and regions (Ferreira, 2013). In a different cultural context, in the following century, modernisnt architects also loooked for vernacular, searching for values of essentialism, rationality and commitment to human and environment (Llano, 1996).

Similar processes took place in Portugal, with the most significant survey work of *Popular Architecture in Portugal* (Sindicato Nacional dos Arquitectos, 1961) having been published in the late 50’s. In this work, the authors recognized that was the "last possible moment to register in all its fullness a world about to disappear”. Recognizing the consistency and the ability of traditional architecture in the articulation of geographical, economic and social factors, this work has become a marked influence on Portuguese architects like Fernando Távora or Siza Vieira.

In parallel, the ethnologist Ernesto Veiga de Oliveira undertakes various studies on traditional architecture that culminated in a posthumous publication (Oliveira & Galhano, 1992). Although focused primarily on the ways of living, this work weaves important considerations about the spatial and territorial aspects of dwelling. Emphasizing, as the Survey, the dwellings of rural settlements, it offers a clear systematization of different morphologies in block-house or patio-house, with ground floor or two storey variants, which will be used in this research as reference for the characterization of farmsteads.

More recently, in 1999,the International Council on Monuments and Sites, in the *Charter on the Built Vernacular Heritage*, defines the vernacular heritage as “the fundamental expression of the culture of a community, of its relationship with its territory”, that “It is a continuing process including necessary changes and continuous adaptation as a response to social and environmental constraints” (ICOMOS, 1999).

In the present days, there has been the awareness that the responses for a more sustainable architecture could be found in a thorough look on vernacular architecture, focusing on form and passive systems to optimize the relationship with the environment. In this sense, the research of Fernandes (2012) presents a classification of strategies and solutions identified in various surveys on popular architecture in Portugal, according to the principles of sustainability and climate region.

Other studies, sought to recognize bioclimatic design strategies of Spanish vernacular architecture, enhancing their recovery and integration in contemporary buildings (Cañas& Martín, 2004) and monitoring *in-situ* some of these strategies, by analyzing and comparing the thermal performance of vernacular face to contemporary buildings (Martin et al., 2010).

3 CASE STUDIES DESCRIPTION

Unlike the Terra Quente Transmontana, where the Mediterranean climate promotes the monoculture with greater economic value - especially almond, olive oil and wine - the Terra Fria is characterized by extensive fields of crops and pasture, in a climate of extremes: a very cold winter - usually with air temperatures between 11ºC and -11ºC - and a hot and dry summer, in average between 29.1ºC and 14ºC(IPMA, n.d.). Here, small rural settlements are predominant, based on a livelihood economy, withagriculture and livestock, always in close proximity to the village, which was the subject of previous studies (Sindicato Nacional dos Arquitectos, 1961; Oliveira, 1992).However, the presence of larger agglomerations, where trade and services assumed great relevance, potentiated different ways of occupation of the territory, as scattered small farms that produced essential goods to supply the city or village.

The highest density of these farmsteads is in the surroundings of Bragança, the most important city in the region, where it is possible toidentify 52 farmsteads with a radius of 5 km from the city(Figure 1). However, documents from the early 20th century point to a much higher number, about 100 (Alves, 1938), in many cases unoccupied, in an advanced stage of degradation and others much adulterated.

These farmsteads arise from the balance between the vernacular landscape and political landscape, as defined by Jackson (1984): the political landscape express needs of community relations and can be indifferent to topography and the local culture, the vernacular landscape "is the result of a slow adaptation to the place, the local topography, climate, soil and people" (Jackson,

1984). In relation to the vernacular landscape, settlement is usually along the water lines, predominantly on the slopes(in the quadrants between south and west) in areas that enable agriculture, pastures and woods (Figure 2). Despite this strong relationship with the land, there is also a relationship with the political landscape, particularly marked by paths and access roads to the city (figure 3). The highest concentration of this typologywithin a 5km radius from the city enabled daily access, on foot,to the market, the reason for the existence of these farms, in a symbiotic relationship with the city.
The unique morphological characteristics of each case is a relevant factor, as it allows to show that vernacular architecture more than applying similar local/regional building solutions always developed site-specific ones. Despite this diversity, the typology has in common the characteristics summarized in Table 1:

Figure 1 Farmsteads location within a 5km radius of Bragança

Table 1. Typology characterization and case-studies presentation

Generic Characteristics	Quinta de Campelo	Quinta do Cano
Isolated but close to town	2,2 Km (30 minon foot)	2,2 Km (30 min on foot)
Adaptation to topography	0,80 m	1,50 m
Orientation favouring South	South-East	West
Close to water sources	100 m	Near the house
Kitchen Garden	Yes	Yes
Diversity of crops	Cereal, Vineyard	Vineyard, Orchard, Olive grove
Livestock	Sheep, Cows, Pigs	Chickens, Ducks, Rabbits

The first case study, Quinta de Campelo, has been referenced since 1697 (Alves, 1938), however, the current configuration results from several changes over time. In the last century, this building was submitted to several transformations that significantly changed it, such as the expansion over the courtyard in the 70s. Morphologically integrates what Veiga de Oliveira&Galhano (1992) call a two-storey Patio-House, the most characteristic of this region. The main front is oriented to the southeast and the building envelope consists of schist walls of approximately 70 cm, with clay mortar partly replaced by cement mortars. Pine wood ceilings create an inhabited attic with the exception of southwest-facing room, just with wood lining. The partition walls are in *tabique* (traditional frame system with wood and clay) and stucco; the main room is separated from the kitchen by a pine wood panel. The original wood window frames were replaced by aluminium windows with double glazing. Due to the implantation in a very low slope zone, cellars and stables, not in use today, are buried only about 80 cm, in direct contact with the soil. The *porta-carral*(oxcart gate),in the northwest courtyard, is protected from the rain by a porch.

Figure 2 Typology distribution according to vernacular landscape and Figure 3 Typology distribution according to political landscape

The second case study, Quinta do Cano, has been referenced since 1864 (Alves, 1938) and it is, until nowadays, in a configuration that isvery close to the original as a two-storey Block-House. The few changes suffered in the mid-'50s follow the traditional construction processes, including the division of the interior spaces with partition walls in tabique and exterior coatings with lime mortar.Although located in a valley, the building takes advantage of the slope of the hillside, to locate the wine cellar — approximately buried in 1.50 meters in the east side. The building envelope is composed of approximately 80 cm thick schist walls, and the most exposed façade is oriented to west. The doors and window framesare still in wood; the floor and the wooden structure are in chestnut wood. All compartments have ceilings, creating an uninhabitable attic, except the kitchen, with no ceilingto facilitate smoke evacuation from the fireplace.Vegetation is usedto shade the courtyard and the existence of awater tank next to the house, helps promotingevaporative cooling in the hot season.

4 ON SITE THERMAL MONITORING

4.1 *Methodology*

Retrieving the methodology of Martín et al. (2010),were monitored in-situ the strategies identified in the vernacular architecture of Terra Fria Transmontana in order to scientifically validate these solutions, that still lack a quantitative assessment, but also to identify common weaknesses in these constructions.

The monitoring conducted in the two buildings focusedon the registration of the temperature and humidity with sensors Klimalogg Pro TFA, with an accuracy of ± 1 ◦ C for the air temperature and ± 3% relative humidity, at intervals of 15 minutes and for periods of 15 days in the hot season.

Monitoring in Quinta de Campelo took place fromJully 14th to 28th of 2013 and the temperature and humidity sensors were placed in the porch of the Northwest courtyard and next to the Southeast façade -, and in four indoor locationsthat are the most relevant in the daily life of the inhabitants: Southeast room, Southwest room, kitchen and cellar, as noted in plans and sections of Figure 5.

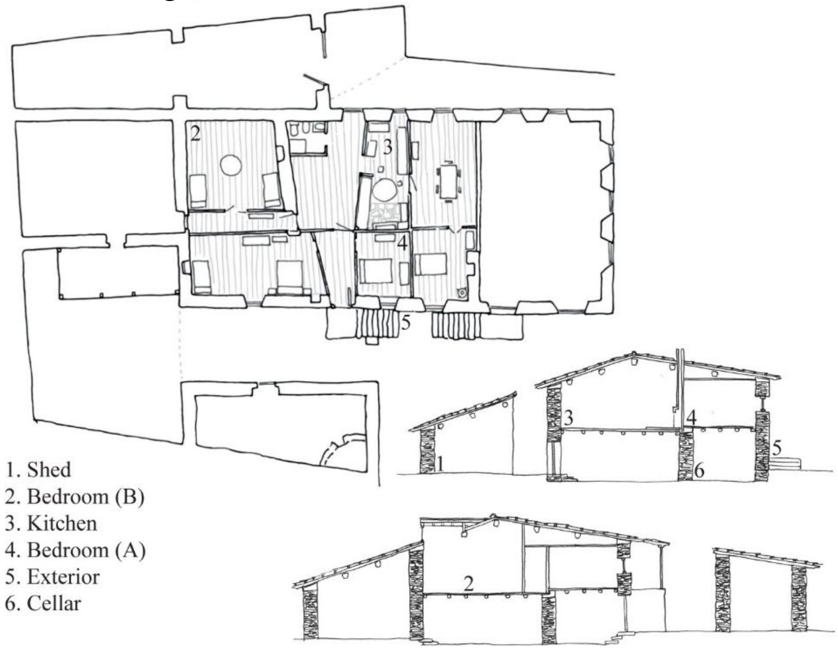

Figure 5 Sensors location in Quinta de Campelo

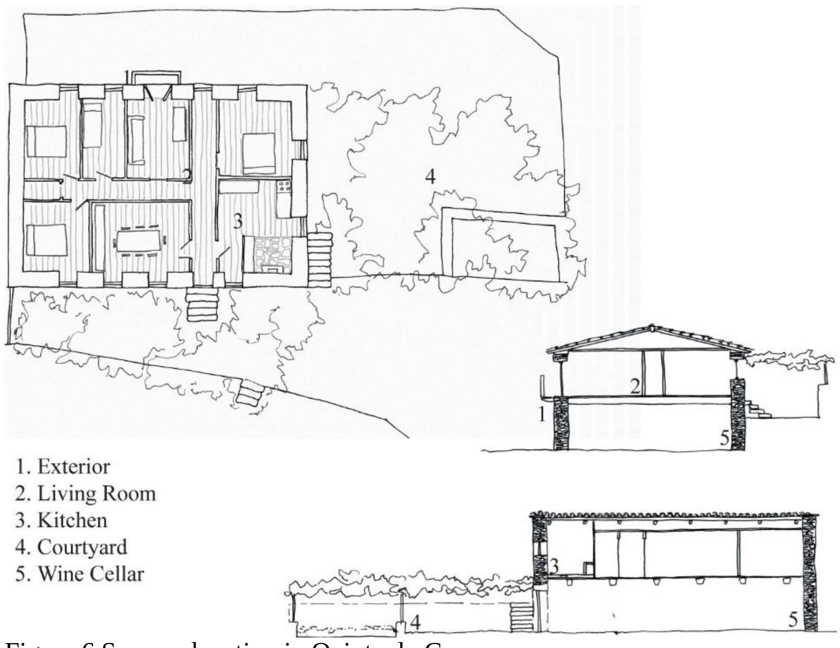

Figure 6 Sensors location in Quinta do Cano

Monitoring in Quinta the Cano took place between July 25th and August 8th of 2013 and the temperature and humidity sensors were placed in the Northeast courtyard and West façade -, and three interior locations: the West living room, kitchen and cellar, as noted in plans and sections of Figure 6.

4.2 *Analysis Of Results*

In Quinta de Campelo, the building has been permanently inhabited for thirty-two.The survey to the inhabitants allowed to conclude that the Southwest room is only occasional used, and that the Southeast bedroom is usually occupied between 9.30 pm and 7.00am; the window is open to ventilate the compartment throughout the morning. The kitchen, social area of the house is usually occupied in the periods between 10.30 am and between 1.00 pm and 7.00 pm and 9.30 pm; the window remains open throughout the night time, as shown in Table 3.

Table 3.Campelo Farmstead – house daily use description

	Period of Use	Natural Ventilation
Kitchen	[10.30 am – 1.00 pm] [7.00 pm – 9.30 pm]	[9. 30 pm – 7.00 am]
Southeast Bedroom	[9.30 pm –7.00 am]	[9.00 am – 12.00 am]
Southwest Room	Ocasional	

Air temperature profiles recorded in the several building spaces/rooms allowed to realize the effect of spaces occupation (Figure 10). In compartments oriented to the west, the maximum temperatures are reached at the end of the day, when there is direct solar radiation. However, the maximum temperature in the kitchen is maintained in a longer period, between 6.30 pm and 8.30 pm, coinciding with the period of use at dinner time.The room West (B) presentsboth the highest temperatures and highest temperature range (Table 4). These resultsare related with the effect of the Sun later in the day and the composition of the roof, with no attic, that facilitates heat lossduring the night. In the Southeast bedroom (A), thermal amplitudes are smaller, with minimum temperatures during the morning, between 8.30 am and 10.30 am, when the window is open to ventilate the compartment.Although the building envelope of this compartment is exposed to solar radiation during the morning, this is only reflected on the interior temperature at the end of the day. The cellar has almost constant values, with an air temperature around 21ºC, and a high relative humidity of about 70%, as shown in Figure 11.

Table 4.Quinta de Campelo – Summary of registered temperatures and relative humidity

	Temperature (ºC)				Relative Humidity (%)	
	MAX	MIN	Range	Average	MAX	MIN
Exterior	32.2	14.1	11.3	23.5	80	17
Shed	29.2	16.9	5.6	24.2	73	26
Cellar	22.1	20.3	0.2	21.4	73	67
Kitchen	29	20.4	4.5	25.2	66	28
Bedroom (A)	28.5	20.3	3.6	25.3	59	28
Bedroom (B)	29.8	20.5	4.7	25.9	62	31

The indoor minimum temperature peak has a time lag of 4 hours, comparing with the outside; the time lag between the maximum indoor and outdoor peak is, on average, 3 hours. On days when the temperature ranges are identical, the difference between inside and outside is lower.Neverthelesswhen the outside temperature fluctuations are larger, this gap may correspond to more than 10 hours, with the maximum and minimum temperatures in the interior to reflect outside temperature decreases from the previous day, probably due to the thermal inertia of the thick schist walls of the building.

Quinta do Cano, is only sporadicallyusedand therefore the use has no significant effect records. Since solar exposure is predominantly West, due to the need to adapt to the topography, the maximum temperatures are reached usually in the late afternoon, between 6.00 pm and 7.30 pm. Exception is made for the Northeast courtyard that, by its more protected solar orientation, reaches higher temperatures between 3.00 pm and 4.00 pm (Figure 12). In addition to solar orientation, the use of vegetation for shading and the presence of the water tank allow evaporative cooling(as demonstrated by the relative humidity values (Figure 13)), which makes this outdoor space more comfortable on the hot summer days. Compared with theoutdoorspaces without cooling strategies, the courtyard has on averagea temperature range 3°C lower than the exterior temperatures and a maximum temperature 5°C lower.

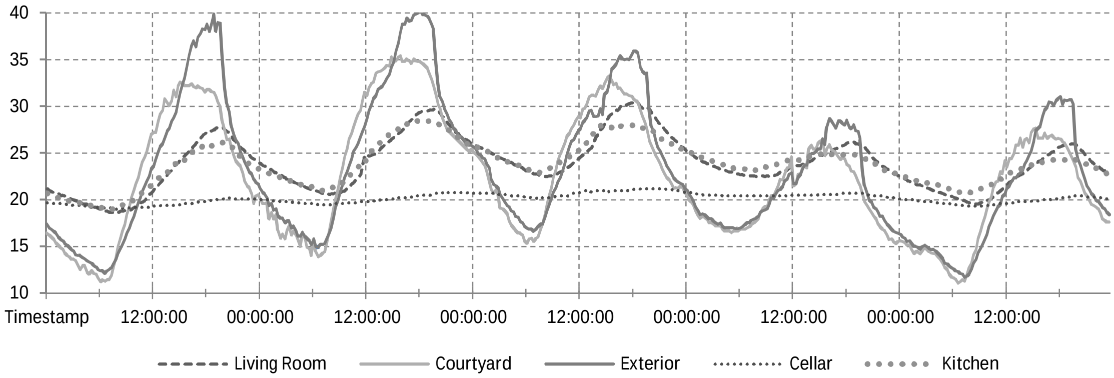

Figure 7 – Quinta de Campelo – indoor and outdoor air temperature profiles between 20th and 25th July

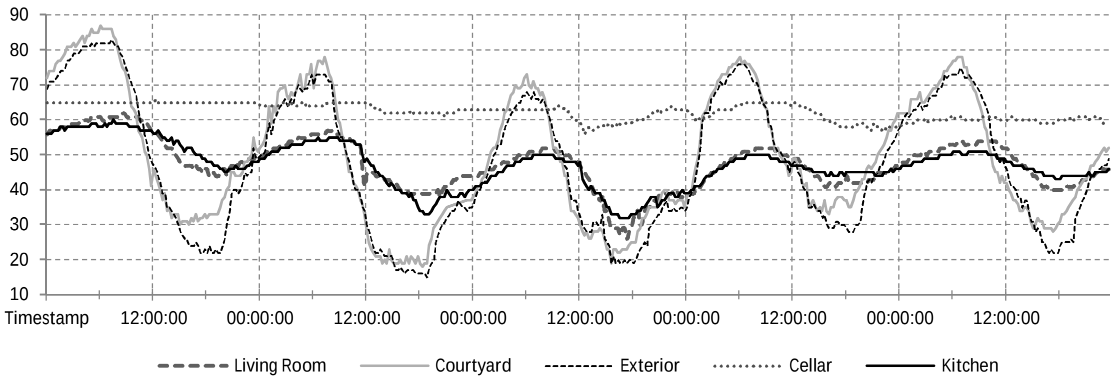

Figure 8 – Quinta de Campelo – indoor and outdoor relative humidity profiles between 20th and 25th July

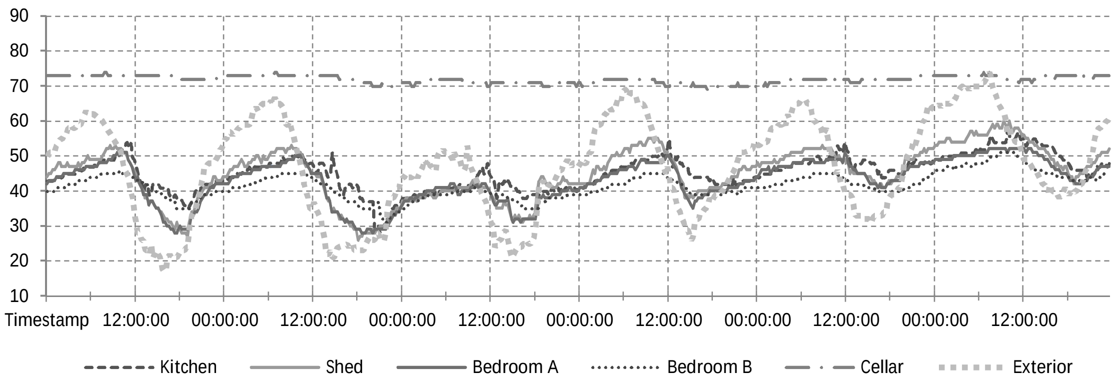

Figure 9 – Quinta do Cano – indoor and outdoor air temperature profiles between 30th July and 3th August

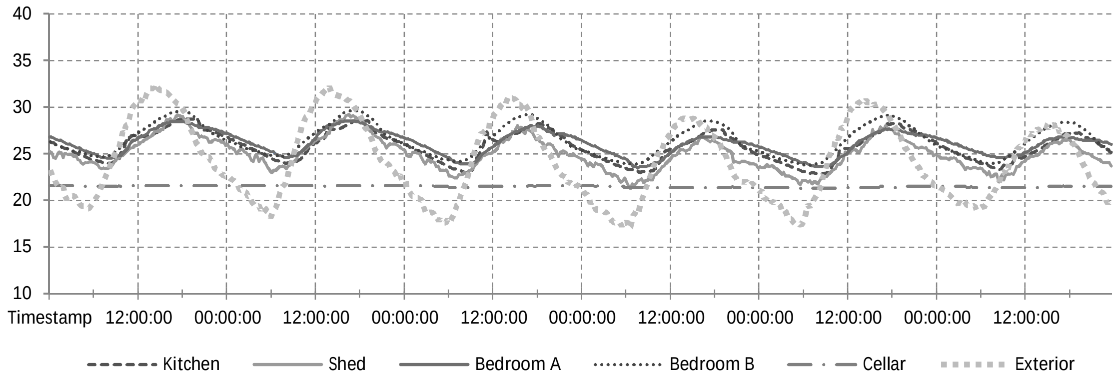

Figure 10 – Quinta do Cano – indoor and outdoor relative humidity profiles between 30th July and 3th August

The cellar, although more buried at East than the samespace in Quinta de Campelo, hashigher temperature variation and lower relative humidity valuesbecause of the building'sorientation that is completely exposed to direct solar radiation during the hottest hours of the day.

In Quinta do Cano, as registeredin the Quinta de Campelo, time lag between the maximum outdoor and indoortemperature peak is of about3 hours; and in the minimum temperature peakis just 2 hours. The air temperature fluctuations are much lower inside than outside, keeping the inside of the dwelling with an average of22.6ºC, even in periods in which outdoor temperature reached up to 40ºC(Table 5).

Table 5.Quinta do Cano – Summary of registered temperatures and relative humidity

	Temperature (ºC)				Relative humidity (%)	
	MAX	MIN	Range	Average	MAX	MIN
Exterior	40.3	10.8	17.8	21.0	89	15
Courtyard	35.4	10.1	14.5	20.3	90	18
Cellar	23.8	18.6	1.1	20.2	66	52
Kitchen	28.6	18.4	3.9	22.9	66	52
Living Room	30.4	18.0	5.9	22.3	64	26

With an average indoor temperature within 23.8°C on hot summer days, the case studies have shown an adequate response through the summer season, mainly due: to the large inertia of the externalschist stoneswalls;to the implemented shadingstrategies;and the evaporative cooling and earth-cooling.

5 CONCLUSIONS

The work carried out until the moment identified a typology of vernacular architecture of the north-eastern region of Portugal that was barely studied until now. In this paper two case studies were identified and characterized (Quinta de Campelo and Quinta do Cano). The study covers their relation with the city and with the surrounding environment and concluded that there is a wise balance between political and vernacular landscape and that these constructions have a thermal behavior that is appropriate to the hot summer in this region. This analysis will be further developed both in on-going monitoring that is being carried out in other case studies and by heating season monitoring.

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The contribute of using vernacular materials and techniques for sustainable building

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ABSTRACT: The use of local materials and techniques is one of the main features from vernacular architecture. When compared with industrially-produced materials, vernacular materials have low environmental impacts, being an alternative for sustainable building. However, industrialization have brought new standardized materials that led to the homogenization of the different building approaches and spawned a universal architecture often with no context concerns and with significant environmental impacts. As for sustainability, vernacular materials have potential to evolve and to be adapted to contemporary needs, helping to reduce the embodied energy and environmental impacts. Therefore, this paper adresses potential advantages of using local materials and techniques in the Portuguese context. Moreover, this paper establishes a comparison between vernacular and industrially-produced at level of environmental indicators (embodied energy and global warming potencial).

1 INTRODUCTION

With the Industrial Revolution, and later with the Modern Movement, the increasing use of new industrially-produced and standardized materials led to the homogenization of the different used construction approaches, until then dependent on available local materials. Their wide dissemination meant that the use of these materials became predominant and traditional techniques and materials fell into disuse. Modern architecture, based on the use of industrially-produced materials, spawned a universal architecture often with no context concerns and very dependent on energy consumption (Montaner 2001; Graça 2000). Beyond this, industrially-produced materials require a high energy-intensity and have considerable environmental impacts (Mota et al. 2012). On the other hand, using alternative materials and techniques, like the vernacular ones (lime, adobe, timber, vaulted ceilings, etc.), the total embodied energy of a building can be significantly reduced, as well as environmental impacts (Venkatarama Reddy & Jagadish 2003; Shukla et al. 2009; Sanz-Calcedo et al. 2012). For example, natural materials such as timber have positive impacts in the overall life-cycle assessment (Mota et al. 2012).

These issues are particularly relevant for the building sector as it has significant environmental impacts, being responsible for almost a third of all carbon emissions (Ürge-Vorsatz et al. 2007) and for consuming more energy and raw materials than any other economic sector (Pacheco-Torgal & Jalali 2012) — with some existing reserves forecasted to last only a few dozen years more (Berge 2009).

Nowadays, energy efficiency and sustainability of buildings are important research issues. As the buildings become more energy efficient during the operation phase, the concern with the embodied energy in building materials is emphasized, thus demonstrating the need to also look at the energy used to produce components (Ramesh 2012). In life-cycle assessment of buildings, environmental impacts associated with all life stages of products are estimated (Bragança & Mateus 2011). One of the components of major relevance in this evaluation is the global warming potential, related to the emission of greenhouse gases (GHG) (Bragança & Mateus 2011), in particular carbon dioxide, which is closely related to energy consumption, or embodied energy (Cabeza et al. 2013). In this topic, LCA includes the operational energy (energy required for the operation of the building, i.e. HVAC, lighting, etc.) and the embodied energy (energy demanded for all processes of production, on-site construction, and final demolition and disposal of materials) (Cabeza et al. 2,013). In the Portuguese context, Mateus et al. (2007) estimated for a conventional building (with a 50-year life-cycle) that the embodied energy in the building materials was of about 10-15% of the total energy consumed during the operation phase. Recently, Pacheco-Torgal et al. (2012) estimated for a set of nearly 100 flats in Oporto that the embodied energy accounted for about 25% of the operational energy for a 50-year life cycle. The same authors consider that with the decrease of the operational energy, by implementing the EPBD directive, the embodied energy will represent approximately 400% of the operational energy (Pacheco-Torgal et al. 2012).

In this sense, reducing the embodied energy in materials is a premise to reduce the environmental impacts and achieve more efficient and sustainable buildings, and it will also (Ramesh 2012). Additionally, it will also decrease the cost of materials and in particular of the buildings as a whole (Ramesh 2012).

Attending to these considerations, and knowing that construction materials have considerably environmental impacts, vernacular materials have from sustainability point of view several advantages that should be highlighted. To better understand the following chapters, vernacular materials should be perceived as those that are locally sourced and used and closely related to specific local conditions (lithology, climate, agricultural crops, etc.), being an identitary factor of architectural differentiation.

2 RESEARCH METHODOLOGY

The research methodology of this study is based on examples present in Portuguese vernacular architecture, using a deductive approach and combining qualitative and quantitative analyses. Thus, this article focuses specifically on the importance of using local materials as well as local construction techniques for sustainable development. Data collection was based mainly on primary and secondary sources. To relate the use of vernacular materials to specific local conditions, several examples were chosen along the Portuguese territory. Moreover, it was established a relation to lithology, climate, agricultural and the tree crops. To assess the contribution of these materials to sustainability, a comparison between some vernacular materials and current industrial materials, in terms of environmental indicators, was carried out.

3 USE OF VERNACULAR BUILDING MATERIALS AND TECHNIQUES

3.1 *The Portuguese context*

As far as Portuguese vernacular architecture is concerned it can be concisely stated that where stone exists people build with this; where there is lack of it, people build with earth, wood or other vegetable materials (Oliveira & Galhano 1992). The materials used were obtained from the geographical area where the buildings were erected. Even in areas of lithological frontier the examples of constructions that use stone from the neighbouring region are rare, because the scarce economic resources of the population did not allow them to access to materials that were not found locally. Only the wealthiest families, or those with some economic ease, could bear the costs of transporting materials (AAVV 1980). The industrialisation brought the habit of using industrially-produced materials, produced far from building sites, what led to the disuse of local traditional materials and techniques.

Even being a small country, Portugal is a territory full of contrasts, not only in climate — with significant variations in air temperature and precipitation (Santos et al. 2002) — but also in the lithological contrast between regions. In Portuguese vernacular architecture it is particularly noticeable that there is an almost perfect correlation between the distribution of the construction materials used and the lithological characteristics of Portuguese territory (Fernandes 2012). To state this fact some examples are highlighted in the following chapters.

3.2 *Advantages of using vernacular materials and techniques on sustainable buildings design*

Vernacular materials and techniques have from the sustainability point of view several advantages that should be promoted. Among these, environmental issues stand out, but there are also social and economical benefits. In this sense, the studies developed by Morel et al. (2001) and Ramesh (2012) concluded that using local materials has environmental and socio-economical advantages, such as: to reduce the amount of embodied energy in buildings; to reduce building costs; and promotion of local economies through local payment of the cost of materials and workmanship. Therefore, it is pertinent to highlight some of the advantages of using certain types of vernacular materials, in opposition to current industrially-produced ones, as one of the paths to achieve a more Sustainable Building.

3.2.1 *Environmental advantages*

Generally, the most relevant environmental advantages related to local materials are: no need of transportation; less energy intensive production process and consequently lower embodied energy and CO_2 emissions; they are natural materials, often organic, renewable and biodegradable, with a life cycle from "cradle to cradle"; low environmental impact during maintenance operations. A brief comparison regarding environmental aspects between local and industrially-produced materials is presented in Figure 1. To compare environmental impacts resulting from the use of materials in construction systems, the total weight of each material must be quantified in advance.

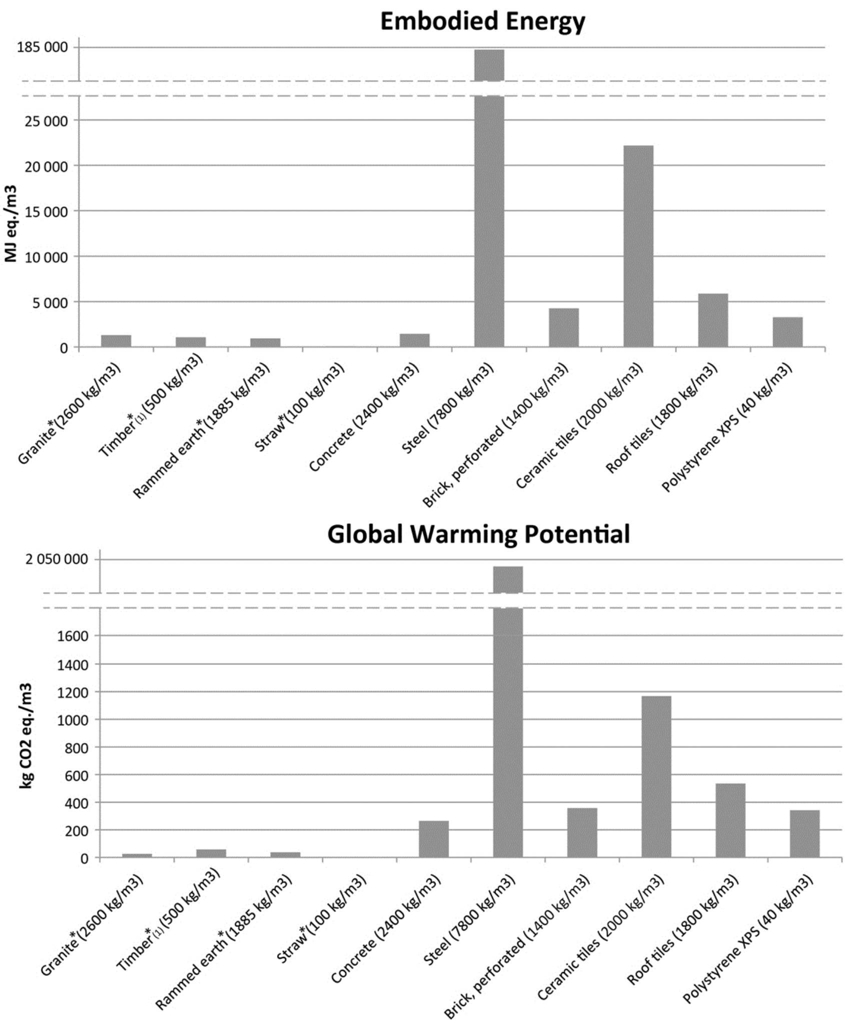

Figure 1. Embodied energy and Global Warming Potential (cradle-to-gate) comparison between some vernacular and conventional building materials. Sources: Bragança & Mateus 2011; *Berge 2009. Notes: (1) Sawn timber, air dried, including planning processes.

In the underneath paragraphs, some advantages related to specific materials and techniques used in Portuguese vernacular architecture will be presented and discussed.

Thatch/straw — In regions of harsh winters and rye crops, as the Montemuro mountains, roofs were made of straw — a waste from cereal production. This coating ensures simultaneous protection against rain and some thermal insulation. This material has the advantages of being a natural material, fully biodegradable, low cost, with a good performance against natural elements, such as rain and snow, as well as insulation properties. There is no specific data on thermal conductivity of the straw applied in roofing solutions, the most common application in vernacular architecture, but it is possible to extrapolate this value from the straw bales (a 60cm thick straw bale has a U-value bounded between 0.12 to 0.09 W/m^2°C) (Sassi 2006). The disadvantages of straw, mainly in relation to ceramic tiles insulated with extruded polystyrene are: lower fire resistance; and the need for periodic replacement, even considering the reduced cost of this process. In a sustainable building design, it is possible to use this material in contemporary applications and it has good potential for integration with new materials (Yuan & Sun 2010).

Rammed earth and adobe — Rammed earth is the most widespread construction technique in the Alentejo region. In this area the good quality of soil for this type of construction technique is reflected in the profuse use of it (AAVV 1980; Fernandes & Correia 2005). The high mass that characterizes earthen constructions allows them to respond appropriately to the scorching summer heat of Alentejo. In coastal regions, as the Vouga estuary, where there is no wide availability of stone but where the alluvial soils and clays abound, the buildings are mostly built of adobe. These are two good examples of traditional materials made from soil of the construction site, an abundant resource with reduced environmental impacts associated with its extraction (Sassi 2006). Although most of these constructions are in developing countries, the number of these constructions in developed countries has been increasing thanks to the importance given to sustainable construction (Pacheco-Torgal & Jalali 2012). Earthen architecture, due to its multiple advantages, continues to make sense in the Portuguese context, especially in areas that traditionally have used this material. Some advantages, among many others, are (Wargocki et al. 1999; Gutiérrez et al. 2005): i) strong thermal inertia ii) ability to influence the quality of indoor air, since it has no VOCs associated; iii) hygroscopic inertia, ie, acting as moisture regulators, retaining it in the appropriate proportions to human health (from 40 to 60%), contributing to the stability of the indoor microclimate; iv) low embodied energy; v) low carbon emissions and low environmental impact; vi) low cost material; vii) if performed on raw earth it can be reused indefinitely. In the case of adobe constructions, the study of Shukla et al. (2009), a life-cycle assessment (LCA) of a dwelling mainly built in adobe, concluded that for every 100m^2 of built area adobe housing presented an embodied energy of 475 GJ, while the conventional housing had 720 GJ.

The disadvantages commonly associated with earthen architecture can be seen from a different perspective, namely: these buildings may have great durability; there are numerous cases with hundreds of years and some over 1000 years old that have reached to the 21st century (Pacheco-Torgal & Jalali 2012); and despite the need for periodic maintenance to ensure its durability this does not entail a high cost.

Research in this field shows that there is still potential to improve the properties of these materials, as exemplified in the study conducted by Pereira & Correia da Silva (2012). The authors demonstrated the possibility of improving the thermal resistance of rammed earth walls, in order to comply with the Portuguese regulations for thermal performance, without changing their environmental characteristics, by adding a mixture of granulated cork.

Vaulted ceilings — The practice of building using this technique began to disappear in the first third of the 20th century with the increasing use of reinforced concrete slabs. However, recent studies have disclosed that the use of this technique in traditional vaulted brick ceilings is more sustainable than conventional concrete slabs. In a life cycle analysis of the traditional vaulted ceilings, compared with concrete slabs, require for their construction 75% less energy, produce 69% less CO_2, have a similar or lower average cost and produce less 171% of waste (Sanz-Calcedo et al. 2012). The same study states that it is a technique that meets the current requirements of sustainability and can be integrated into current construction techniques, being very economic and functional. The lessons learned from this study come to support that vaults continue to be viable in contemporary construction, in addition to the significant contribution to the sustainability of the building stock. The need for more skilled workmanship is presented as a disadvantage but, taking into consideration that the cost of these structures is not superior to conventional concrete slabs, the allocation of structure cost to manpower appears to be an added value. In order to have this technique properly valued and spread it is necessary that its advantages are disseminated among all construction stakeholders and that new professionals can be trained in the implementation of this technique.

Loam roofs — In the island of Porto Santo there are some examples of vernacular constructions that use loam roof systems. This system is locally identified as “salão”. This kind of loam from the island is distinguished by its dynamic physical behaviour, perfectly suited to the climate of the island (high temperatures, dryness and low rainfall), i.e., in summer it cracks allowing continuous ventilation; in winter, with the first rains, and due to its natural gum, it quickly aggregates becoming waterproof (Mestre 2002). Besides the highlighted advantages it is also an economical and easy to maintain material (Mestre 2002). Additionally, it is an environmentally friendly material and although there is no detailed published data about this technique, by affinity with other materials such as rammed earth and adobe, it is possible to say that it has low embodied energy. Its application in the construction requires no special treatment and its maintenance is carried out with the simple application of another layer of loam. This technique is currently in disuse on the island, where the use of ceramic tile is dominant (Mestre 2002). In order to protect and reintegrate this technique, future economic and feasibility studies are needed to scientifically sustain the suitability of its use in the specific context of Porto Santo.

Timber —This building material is omnipresent in Portuguese vernacular architecture. Depending on local availability its use in construction ranges from occasional use as structural element to the integral construction of housing. As for the latter, coast’s wooden buildings “palheiros” and the houses of Santana are noteworthy examples. Forest cover of these areas helps obtaining this material and allows the construction to be almost entirely made of it. In the coast, particularly in the closest constructions to shore, timber construction is the most appropriate in relation to the sandy soil and sea moisture (AAVV 1980). The advantages of wooden construction today, which were already visible in the vernacular examples, are: it is renewable, biodegradable and recyclable; it requires little processing to be used in construction; and it allows prefabrication — which contributes to reduce construction waste. Depending on the method of construction we can also consider the chance of a more efficient and economic maintenance, with the possibility to replace piece-by-piece, as in "palheiros", without changing the structure of the building. Since it requires low processing to be applied in construction it has a relatively low embodied energy. The study of Coelho et al. (2012) on the life cycle assessment of a wooden house, reveals the importance of using local resources of raw materials and local production to reduce transportation needs that affect the environmental performance of this kind of construction. Having in mind the abovementioned advantages of wood construction, this construction system should be encouraged, especially in places where this is suitable. The incentives to wood construction can also be an incentive for sustainable forest management. This one needed to tackle climate change that is enforcing new challenges to forest preservation, including the maintenance of viable ecosystems to ensure the productivity and retention of forest environmental services (Silva 2007). The planning of forestation still has several environmental advantages, including the ability to increase carbon sequestration, help to regulate the climate, control soil erosion, retain water in the soil and create conditions for the development of biodiversity (fauna and flora) (Marques 2008).

3.2.2 *Social and economic advantages*

To achieve a truly sustainable development it is also necessary to take into account the social and economic dimensions. In the construction sector it is critical to have the ability to understand these three dimensions. Edum-Fotwe & Price (2009) divided the process of building in three levels — urban, buildings and materials — and for the latter defined a set of social parameters to be considered for improving the sustainability of the built environment, such as: employment; health; safety; wellbeing; education and training skills; and culture/heritage. Analyzing, even superficially, the potential benefits of using vernacular materials, we can conclude that it fits all the social parameters defined in the abovementioned study.

Regarding employment, several studies report the great need of more and skilled workmanship as a disadvantage of traditional construction techniques. But taking into account that the direct cost of these materials and structures is often inferior to that of conventional building systems, the allocation of the structure cost to manpower seems to be an advantage. The distribution of the income among more stakeholders is socially fairer than just allocating it to the price of a material. The local production of materials is not only economically cheaper, as it also enables creating jobs for unemployed people (Sanya 2007 cited in Pacheco-Torgal & Jalali 2012). Additionally, the need for skilled workmanship leads to education and training on these vernacular building systems, contributing not only to improve the qualifications of the several construction stakeholders but also to preserve and continue a local heritage and cultural legacy. The education in vernacular building systems is also crucial for politicians, sociologists and economists who make decisions about the built environment (Oliver 2006).

The fact that these materials came from the same local climatic conditions where they were applied has the following advantages: greater adaptability, economy and increased durability (Singh et al. 2011).

In matters of health, advantages are mainly related to the fact that these materials are of natural origin, with low toxicity, no volatile organic compounds, some of them with properties capable of regulating the temperature and indoor air quality (Berge 2009), as referred in the example of earthen architecture.

In terms of economy, Goodman (1968 cited in Berge 2009) argues that an industry of ecological construction must have their production units near the place of consumption, using local renewable resources, focusing on processes that require little energy and produce reduced pollution. Furthermore he argues that decentralization can increase corporate decision-making centres and have a clearer idea of the context in which they labour, especially relationships between decision-makers and local resources. In this sense Oliver (2006) also argues that the discourse on sustainability is too oriented at the cities scale, requiring the implementation of decentralization policies in economies that contribute to the regeneration of rural areas. The redevelopment of these areas could be a way to stop the expansion of cities.

In order to promote and implement this kind of intent it is necessary to involve the local authorities. Each site has its own idiosyncrasies that must be taken into consideration in the definition of specific policies adapted to its context (Dumreicher & Kolb 2008). Supporting sustainable local development means also preserving a cultural heritage of construction knowledge inherent to regions.

4 CONCLUSIONS

In the past, due to lack of technological solutions capable of producing more advanced materials and to transport them over long distances, materials used in vernacular constructions had low-tech profile and were restricted to those available on sites. These were mostly natural, had low processing, low embodied energy and consequently reduced environmental impacts. In contrast, today’s technology allows the production of hi-tech materials, available on global scale, although usually requiring an energy-intensive processing. In addition, centralized production of these materials implies large energy requirements for transportation, from the extraction point of raw materials to the distribution of finished products. Taking into consideration that traditional materials are closely related to local conditions and have significantly less environmental impacts and embodied energy than current construction materials, their use means a potential to reduce impacts throughout the life-cycle of buildings, in a "cradle-to-grave" approach and, in some cases, a “cradle-to-cradle” approach.

Analysing the abovementioned vernacular examples it is noticeable that the plurality of the Portuguese territory offers a profuse expression of different vernacular building materials. These examples illustrate a close relationship with the characteristics of the sites (lithology, climate, crops and forest cover) where they are used. Materials and techniques used in Portuguese vernacular architecture have potential for contributing positively to the sustainability of the built environment. Nevertheless, there is still a lack of information regarding Portuguese context on this subject. Therefore, although vernacular construction materials are perceived to be more environmental friendly, there are no scientific-based studies that prove this better environmental performance. So, more studies are needed to interpret and understand the best vernacular techniques so that they can be improved and transposed to contemporaneity, in order to be scientifically validated, giving them credibility and encouraging their use among the stakeholders in the building sector.

Thus, to achieve sustainability, architecture should seek integration between tradition and contemporaneity, using the best of both in technologies and materials. Beyond the environmental issues, promoting the use of local materials may have a positive impact on local social and economical developments. It is up to designers to use their creativity to improve and adapt these techniques to new functional building requirements.

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Chapter 4

Design and Technologies for Energy Efficiency

Urban Form and Daylighting: Examining daylighting conditions with regard to building block typologies

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ABSTRACT: The enhancement of visual comfort conditions in buildings not only improves the quality of life of the inhabitants, but also contributes to the reduction of cooling and lighting energy loads. Within this context, daylighting has been introduced as an important parameter in the majority of building energy performance regulations across Europe. However, in dense urban tissues daylighting is largely affected by the existing urban geometry; form parameters, such as distances between buildings, road widths and building heights are imposed by the existing town layout plan and building regulations. The objective of the present study is to identify the impact of urban geometry parameters on the formation of indoor daylighting conditions in the Greek city context. It is focused on the urban block level and concerns the examination of a number of typical Greek urban blocks which are analyzed using 3-D simulation models in order to compare the derived daylight levels. Among the examined factors are the building ratio, the mean block height, the road width etc. The results of the study indicate that there is a strong relationship between the urban layout and the daylight availability, the magnitude of which is quantified with respect to the urban geometry characteristics. Such information is valuable, since it indicates the quality of daylighting in buildings located at areas with similar urban geometry and at the same time it can be used for predicting the performance of potential daylight systems that need to be integrated on urban buildings for improving their indoor visual environment.

1 INTRODUCTION

Visual comfort conditions in buildings are a basic factor not only for the quality of life of the inhabitants, but also for the reduction of energy consumption in buildings. The present paper intends to examine the impact of urban geometry parameters on the formation of indoor daylighting conditions in the Greek city context. Recent studies on the urban block level have tried to evaluate sustainability and to quantify daylight levels of different urban block forms (Adolphe 2001), (Steemers et al 2000), (Maizia et al, 2009), (Salat, 2011), (Salat 2009). Analysis of building form archetypes was first launched by Martin and March (Rati et al, 2003) who examined a number of simplified or archetypal forms. This choice allowed them to limit the complexities found in real urban textures and to examine and compare the impact of geometry. More recently, Cheng et al (2006) examined the impact of geometry factors to solar potential in an effort to prove that the compact city can be sustainable. Case studies and hypothetical scenarios of different building layouts have also been examined by R. Compagnon (2004) in Switzerland (Fribourg), revealing large variations of the potential solar energy collection on building facades.

2 THE METHODOLOGICAL APPROACH

The present paper intends to investigate the influence of the urban space morphology on the indoor daylighting conditions. More specifically, different urban block configurations which are representative of the Greek urban tissue are examined; an urban block is defined as a group of contiguous land parcels delineated by streets or public spaces. The daylight conditions prevailing in the indoor spaces of selected buildings that are part of the examined building blocks are calculated with the help of a simulation tool. In the next sections, the typologies of the examined urban blocks are described and the calculation procedure is presented in detail.

2.1 *Description of the urban block typologies*

Three typical urban block forms (Type I, II and III) are examined in the present study in order to draw conclusions concerning the influence of urban geometry on indoor dayilighting. The typologies under examination are based on a previous study (Tsirigoti, 2010) and are part of a larger set of typologies, which characterize the Greek urban tissue.

The typologies belong to the subcategory of the continuous building system and have a rectangular layout plan (55.00 m x 55.00 m). Although their overall surface area is the same, they differentiate on their geometry factors, i.e. the dimensions of the uncovered space, which change according to the coverage ratio, the mean block height and the building ratio (Fig. 1).

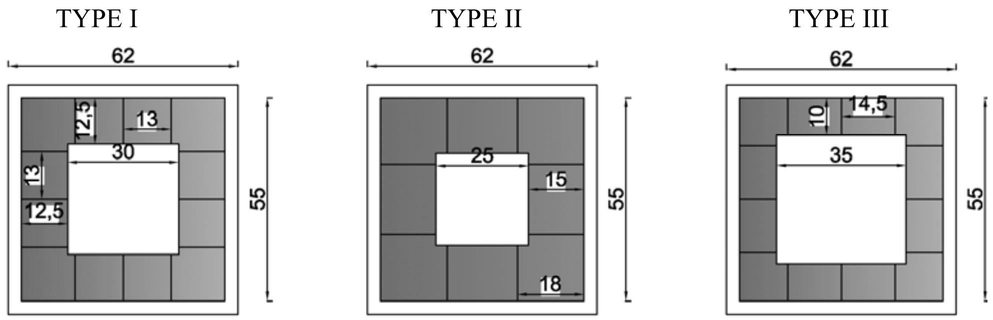

Figure 1. The layout plan and the geometrical characteristics of the three examined typologies.

Each examined urban block has a different number of floors, which results in different block heights (Table 1). These typologies obviously correspond to building blocks which are located in different areas of the urban tissue; for example, Type I which has a higher building density is mostly expected to represent urban blocks located near the central areas of the city, while Type II and III are expected to be located in more distant areas.

Table 1. Geometry factors of the three typologies.

	Height (m)	Number of floors	Width/Height ratio	Coverage ratio	Building ratio
TYPE I	19.00	6	0.84	0.70	4.20
TYPE II	7.50	2	2.13	0.80	1.40
TYPE III	13.00	4	1.23	0.60	2.40

It must be noted that the first floor of Type II is elevated at a level of 1.50m, due to the existence of an underground floor. On the contrary, Type I and Type III have no underground floor and their first floor is elevated at a height of 4.00m above the ground floor level.

The surrounding urban blocks in each case are considered to have the same geometrical characteristics as the ones under examination and therefore they have the same height as the examined urban block in each case. In addition, the surface reflectance of the neighboring buildings is considered to be identical to the one of the examined buildings, while the surface reflectance factor for the remaining elements of the built environment was set to an average value of 0.3. Road width is considered to be similar for the three typologies which is 10.00m, while pavements were considered to have a width of 3.00m. This means that the distance between the building's balconies is 13.40m and the distance between the facades is equal to 16.00m (Fig. 2). The geometry factors of the three urban block typologies are presented in Table 1.

Since daylighting is examined within the context of an enclosed space (room), it was necessary to define the layout plan for each building in order to establish the typical apartment layout plan. The typical urban building layout is not described thoroughly in this study as it is beyond the scope of this paper; an indication of the indoor space configuration is shown in Figure 2 for one of the examined urban blocks (Type II).

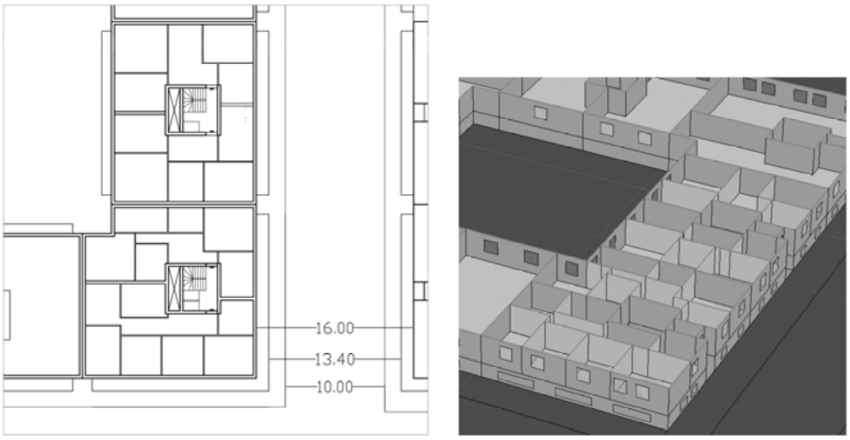

Figure 2. Layout plan and 3D cut away section of the examined buildings of Type II.

TYPE I TYPE II TYPE III

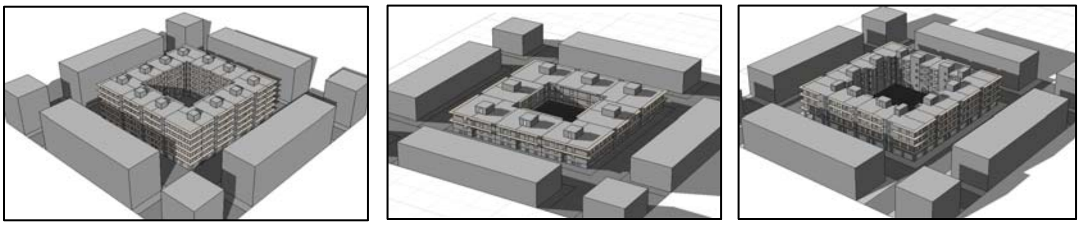

Figure 3. 3D Computer model of the three typologies.

Due to the symmetrical plans of all three urban blocks only two buildings per urban block were examined. The first building examined is located at the corner of the urban block and the second is the adjacent building located in an intermediate position. The daylight conditions prevailing on the reference plane of the rest of the buildings of each urban block is expected to be similar due to plan symmetry, given the fact that overcast sky conditions have been chosen for the daylighting simulation, representing the worst case scenario.

2.2 *Description of the calculation procedure*

For the calculation of daylight levels three 3-D simulation models were created in Autodesk Ecotect 2011, each one corresponding to one of the building blocks (Fig. 3). Material properties have been obtained by the Technical Guidelines issued by the Technical Chamber of Greece for the implementation of the Regulation for the Building Energy Performance and are considered to be typical for the built environment of the Greek city.

Climatic conditions of the city of Thessaloniki (latitude 40.5°, longitude 23.0°) were considered in the analysis. Daylight factors and illumination values under overcast sky conditions have been calculated, assuming that the design sky illuminance is equal to 7810 lux.

Daylight levels are calculated for each floor of the three typologies taking into account a room depth of 6.00m. It should be noted that the plan depth that was chosen for the simulation of the daylight levels is determined by the layout plan of each building. In the present study it has been assumed that the layout and the plan proportions of each building that constitutes the urban block define rooms with different plan depths with access to daylight and visual comfort requirements.

The simulations were performed only for the part of the buildings with a residential use; this means that the ground floor levels have been excluded from the analysis, since this floor usually houses commercial uses.

3 PRESENTATION OF THE RESULTS

3.1 *Daylight levels*

The illumination levels derived for each floor of the examined urban blocks are displayed in Figures 4 to 6. They range from 0 lx to 1400 lx at a step of 100 lx, but different levels of the minimum and maximum values prevail in each case.

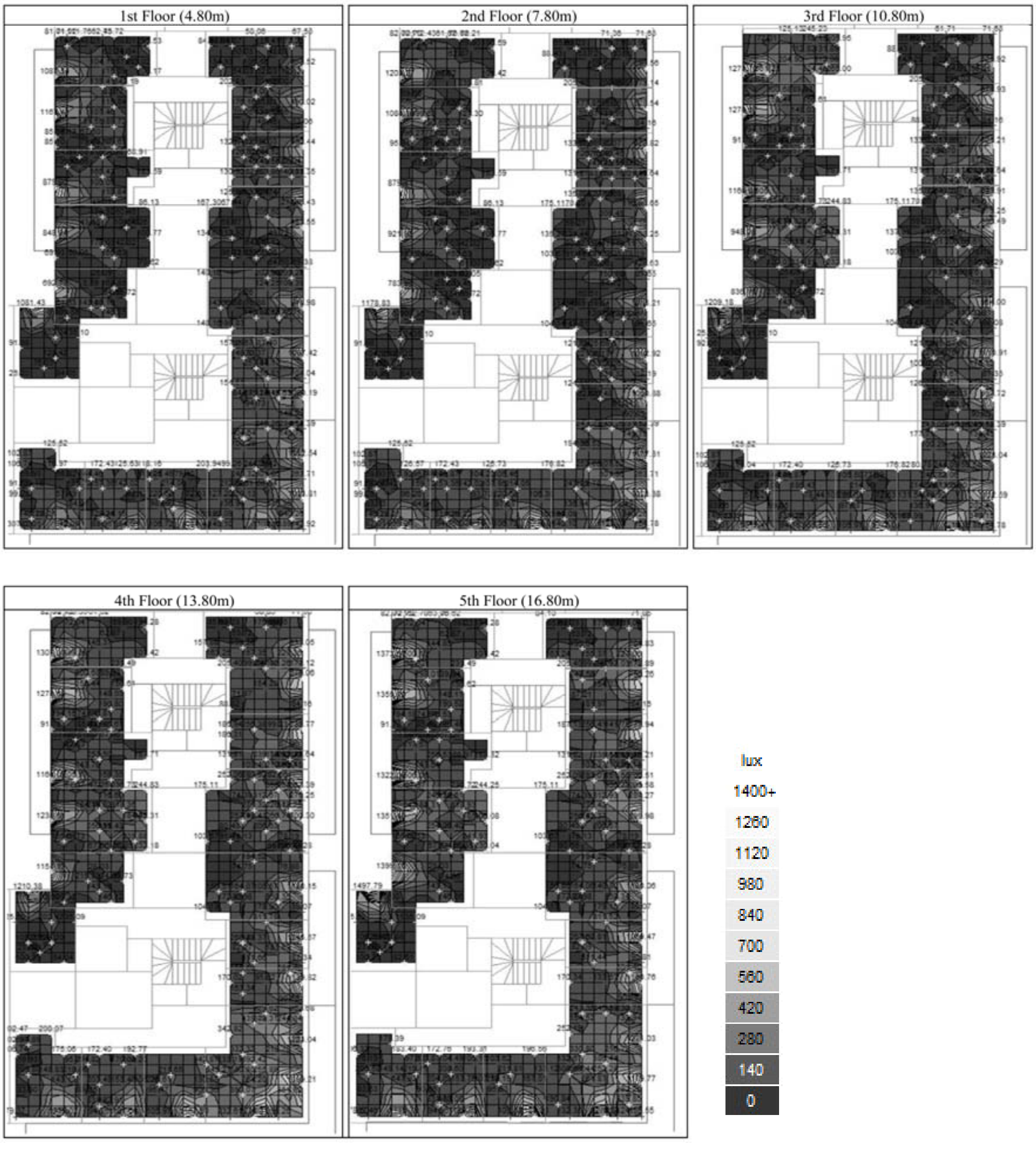

Figure 4. Daylight levels calculated for each floor of building block Type I.

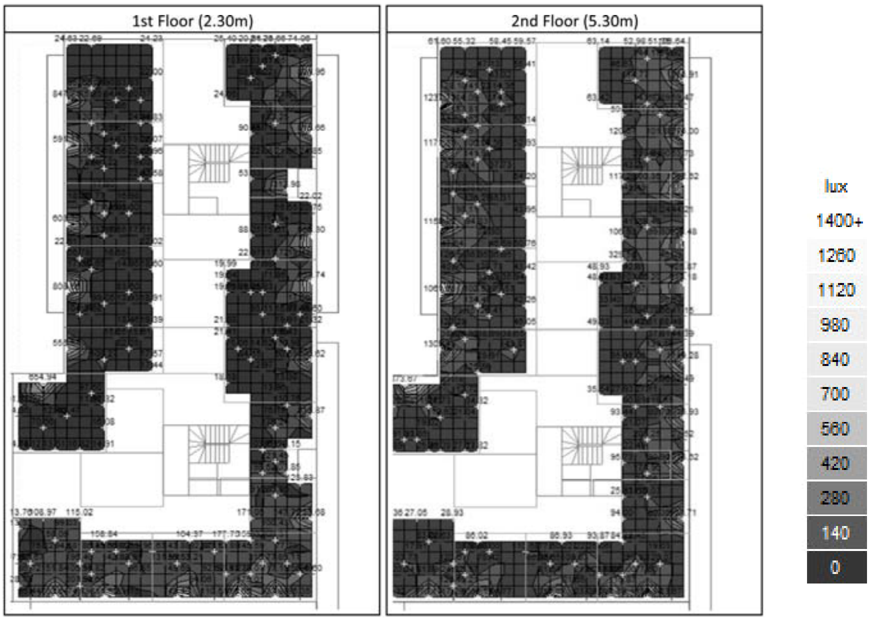

Figure 5. Daylight levels calculated for each floor of building block Type II.

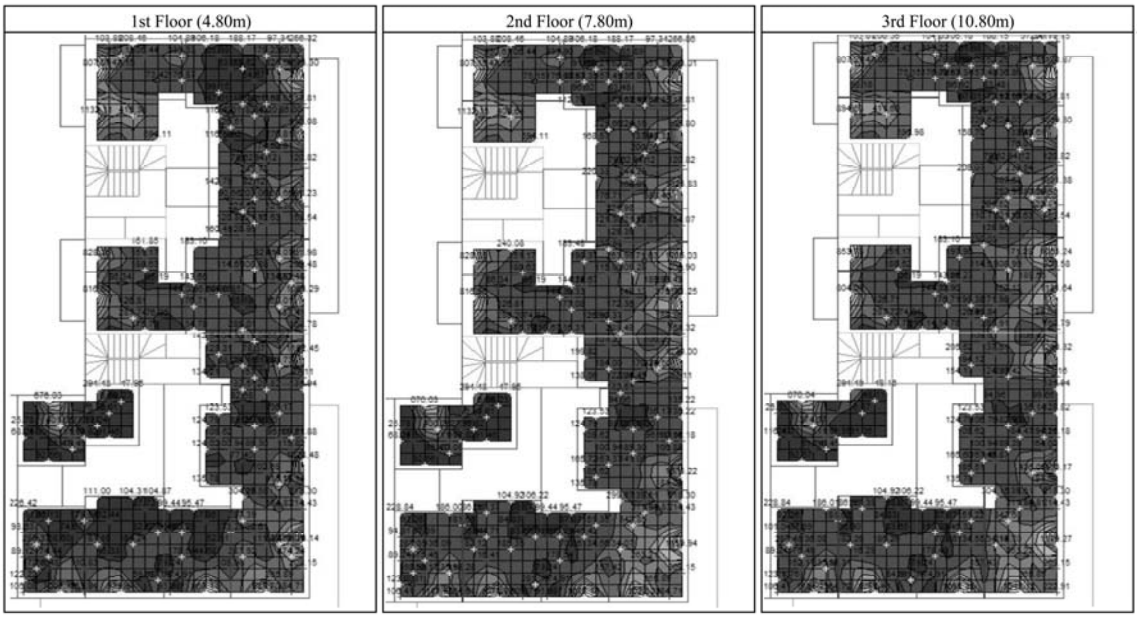

Figure 6. Daylight levels calculated for each floor of building block Type III.

The average values of illuminance prevailing on the reference plane of the examined apartments of each block type are presented in Figure 7. It can be easily discerned that the urban form is a decisive factor when it comes to dayligthing, as the three typologies present a significant variation on the daylight levels. In each typology the average illumination values increase as the floor elevation increases. The increase on the daylight levels between the floors is not proportional; for example, for the Type III block, the average illumination seems practically unaffected among the lower floors (1st and 2nd) and among the higher floors (4th and 5th). When the lower floors are considered, the surrounding buildings obstruct the view to the sky vault, resulting in lower daylight levels, which are mostly determined by the component of the internally and externally reflected daylight (Tsikaloudaki, 2007). In higher floors, the view to the sky vault becomes less confined, allowing for higher daylight levels. The fact that the upper floors have practically an unobstructed view to the sky vault justifies the minor differences observed in type I and III.

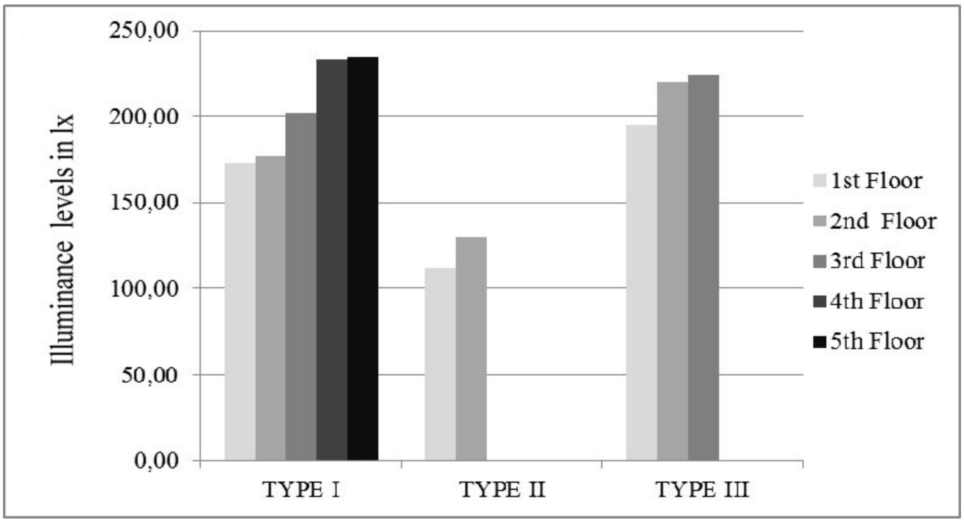

Figure 7. The average illuminance levels values for each floor of the three examined urban block types.

The fact that the uncovered space is wider than the road differentiates the daylighting between the rooms facing the road and the uncovered space. In Figure 8 a detailed view of the illuminance levels prevailing on the reference plane of two similar rooms located on the first floor of Type III, one looking on the inner uncovered space (left), and one looking on the road (right) is displayed. If we examine the illuminance levels near the window of each room, we can remark that those of the left room (looking on the inner uncovered space) have much higher values than the ones of the right room. The same finding is derived for all three building block typologies, indicating that the apartments overlooking the inner uncovered space are not necessarily worse lit than the ones on the main building facades.

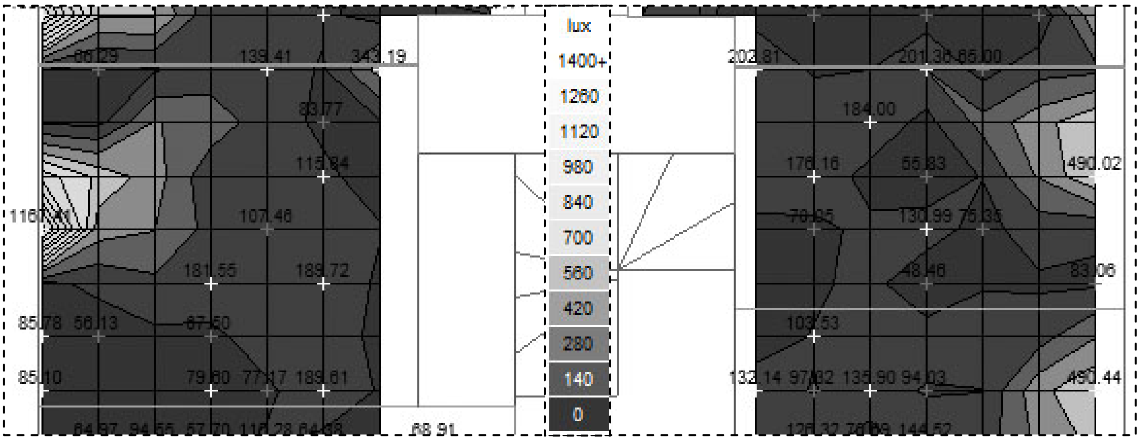

Figure 8. Detail of the illuminance levels of the first floor of Type III, for two similar rooms, one looking on the inner uncovered space (left), and one looking on the road (right).

In addition, it is remarkable that Type II seems to present the smallest values of dayligthing levels despite the fact that it is the urban block with the lowest building height. The relatively narrower, inner uncovered space of the urban block (inner court), and the larger plan depth, have contributed in these unfavorable daylight conditions.

This means that for the specific cases examined the building height factor is not as important as it is the coverage ratio factor concerning daylighting. This is not suggested to be a general rule, as the presented urban blocks have a relatively large road width and a low height of the building blocks in the surrounding area. More studies need to be done in order to examine the impact of road width on daylight levels, considering smaller road widths, which will definitely create more unfavourable daylighting conditions.

Moreover, from the three analyzed urban block typologies we can observe that urban blocks with larger plan depths tend to have worse indoor daylight conditions. A similar view is presented from Dekay's study (DeKay, 2010) on atrium buildings, who suggested that the 2.5h rule is not adaptable in all cases and proposed a different method in defining the optimal building depth. It is evident that more research needs to be done in order to generalize such conclusions and to quantify the optimum plan depth for daylighting.

4 CONCLUSIONS

The results of the current paper have demonstrated that each building block type has a completely different profile, relating its form and geometry to daylighting conditions. In fact, it was derived that the urban form is a decisive factor for daylighting conditions, as the three typologies examined present a significant variation on the daylight levels prevailing indoors. In each typology the average illumination values increase as the floor elevation increases. However, the increase on the daylight levels between the floors is not always proportional. It is obvious that the relatively narrower, inner uncovered space of the urban block (inner court), as well as the larger plan depth contribute in the creation of unfavorable daylight conditions.

Apparently the interpretation of the profile of each block type is not an easy task as sometimes parameters of geometry are contradictory when it comes to daylighting issues. For example higher buildings reduce the access to daylight to the lower floors, but the overall daylighing conditions of an urban block with a relatively larger block height are not necessarily worse than those of a smaller height urban block.

The typologies examined in this paper constitute a very small part of the building block types that exist in the Greek city, since the urban tissue cannot be easily described in its complexity. However, the presented cases suggest that urban block morphology and urban block planning should consider the daylighting conditions of building blocks. It is obvious that there is a lot of research that needs to be done in order to reach more general conclusions and proposals about the enhancement of daylighting conditions in our cities; however the importance of the urban block analysis is a basic step towards the assessment of the existing built environment. Nevertheless, the formation of the urban block influences not only the visual environment prevailing indoors, but also almost every aspect of building physics; i.e. solar exposure, ventilation, acoustics, etc. A holistic approach will not only lead to the enhancement of indoor comfort and living quality, but will also contribute significantly to the optimization of energy and environmental performance, one of the major objectives of the sustainability policies in the European countries.

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Lighting Design: Aligned to Demands for Lower Energy

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ABSTRACT: Lighting design is one of the fastest changing areas in building engineering. It has evolved significantly in recent years due to changing technology and demands for improved quality, reduced energy and sustainability. New recommendations change previous demands for equal illuminance across an entire space and make new recommendations for qualitative metrics and distribution of light, combined with demands for control and energy efficiency.
This is an exciting and challenging time for the lighting industry. We are challenged to provide holistic and robust solutions that maximize the benefits of new technologies whilst protecting our clients from poor quality lighting products and installations. This paper reviews latest developments in lighting, international research and provides a skeptical but leading edge view on where lighting design for building interiors is headed.

1 INTRODUCTION

This paper reviews how recent changes to the Code for Interior Lighting (2012) issued by the Society of Light & Lighting (SLL) are affecting lighting design in the UK and Ireland and internationally in Europe and wider afield where the SLL Code is used. A critical view is offered which argues that conforming to codes and standards does not always produce good lighting design. It is argued that good perceptions of lighting are related to levels of daylight and that this must be integrated with artificial lighting in such a way as to produce a holistic low energy building.

Lighting design is one of the fastest changing areas in building engineering. It has evolved significantly in recent years due to changing technology and demands for reduced energy and sustainability. New recommendations change previous demands for equal illuminance across an entire space and make new recommendations for qualitative metrics and distribution of light, combined with demands for control and energy efficiency.

Increased demands for more daylight linked to improved lighting control and the introduction of the Lighting Energy Numeric Indicator (LENI) through EN 15193 are increasingly leading to more holistic design with the need for architects, engineers and facilities managers to work more closely to provide this holistic design.

LED lamp technology is expected to be a €65billion industry by the 2020s with this technology improving at an exponential rate. But this technology can be expensive and is not without problems.

This is an exciting and challenging time for the lighting industry. We are challenged to provide holistic robust solutions that maximize the benefits of new technologies whilst protecting our clients from poor quality lighting products and installations. This paper reviews latest developments in lighting, international research and provides a skeptical but leading edge view on where lighting design for building interiors is headed.

2 CURRENT GUIDANCE, RECENT CHANGES AND LIMITATIONS OF GUIDANCE DOCUMENTS

In the UK and Ireland, as well as many other parts of the world, the foremost authority on interior lighting is the Society of Light and Lighting (SLL), previously named the Illuminating Engineers Society and founded in 1911 (Loe et al, 2009). It has set guidance for the industry since 1936 and writes a wide variety of design guides for the lighting sector, which are widely adopted throughout Europe and other parts of the world. The SLL's Code for Lighting and accompanying Lighting Handbook provide a summary of lighting standards and offer further qualitative guidance, which combines to provide a comprehensive text on lighting. In recent years, the European Committee for Standardization (CEN) has also set standards for all countries in Europe. Although there are many standards, in the foreground are EN 12464 Lighting for Workplaces and EN 15193 the Energy Performance of Buildings Directive. In EN 12464 minimum requirements for lighting are laid down for both interior (part 1) and exterior (part 2) lighting. EN 12464 specifies many quantitative criteria, but the most prominent are maintained illuminance, uniformity, color rendering index and unified glare rating (CEN, 2011a). Maintained illuminance is the quantity of light that an installation will provide at the end of a maintenance cycle, uniformity is the ratio of the average illuminance compared to the minimum illuminance, color rendering index is a measure of the appearance of colors under certain light sources and unified glare rating is an estimation of visual comfort. Within EN 15193, a specific method for the calculation of lighting energy consumption that goes beyond W/m^2 is described.
In recent years, standards have changed. The full implications of this are explained elsewhere (Duff, 2012), but the main changes are:

- increased room surface reflectances,
- minimum quantities of illuminance on major room surfaces,
- a move from illuminating an entire horizontal space at working plane height to focusing light onto where it is needed,
- the introduction of metrics which account for illuminating objects and peoples' faces within a space and the proposition of an alternative method for calculating energy consumption that better accounts for use of daylight and control mechanisms (CEN, 2011a)(CEN, 2011b)(CEN, 2006).

Increased room surface reflectances will allow for an increased quantity of reflected light, which will increase the brightness of a space (Duff and Kelly, 2013). Specifying a minimum quantity of light on the major surfaces of a space will ensure that there is enough light available so that reflected light will contribute to the appearance of the space (CEN, 2011a). It is no longer recommended to illuminate an entire space at working plane height to a given illuminance level. It is now suggested that lighting designers work with their design team to finalize the task area within a space and illuminate this to a suitable illuminance, with the remainder of the space illuminated to a lower illuminance (CEN, 2011a). The aims of this are to provide visual interest, which has been shown to increase occupant satisfaction within spaces (Boyce, 2003), and reduce energy consumption.

The introduction of cylindrical illuminance and modeling index are stated as being "a big step forward in recognizing the importance of the visibility of objects, particularly peoples' faces, within a space" (SLL, 2012). Minimum levels of cylindrical illuminance and an appropriate modeling index will highlight objects, reveal textures, aid facial recognition and allow for better integration of electric lighting and daylight (CEN, 2011a)(SLL, 2012)(Nassar et al, 2003).

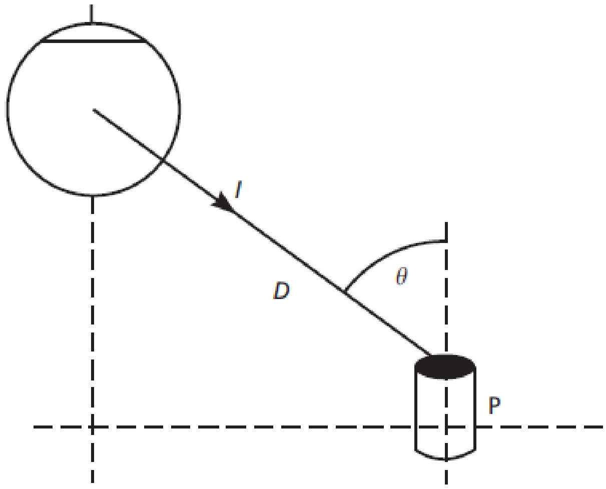

Figure 1. Cylindrical Illuminance (SLL Code)

Figure 1 above illustrates illuminance considered on the cylinder; this is an important metric of light when considering modeling. Figure 2 below illustrates diffuse lighting, directional lighting and a combination of side and diffuse lighting respectively. Both illustrations are from the SLL Code for Lighting.

Figure 2 Modeling illustrated

Standards, however, do have their limitations. In a search for what exactly the purpose of lighting guidance is, Boyce attempts to define lighting quality; *bad quality lighting is lighting which does not allow you to see what you need to see quickly and easily and/or causes visual discomfort. Indifferent quality lighting is lighting which does allow you to see what you need to see quickly and easily and does not cause visual discomfort but does nothing to lift the spirit. Good-quality lighting is lighting that allows you to see what you need to see quickly and easily and does not cause visual discomfort but does raise the human spirit* (Boyce, 1998). He later proceeds to show that lighting guidance will only eliminate bad lighting and produce indifferent lighting (Boyce, 2013). It will do little to produce good quality lighting (Boyce, 2013). Boyce suggests that at present, to produce good quality lighting, a team of a talented architect and a creative lighting designer are necessary (Boyce, 2013). This shows the limitations of lighting guidance and standards; simply following them will not produce good quality lighting. Boyce explores methods which may bridge the gap between indifferent and good quality lighting and proposes that if none of these are accepted in the future, then good quality lighting will only be available to those that can afford the services of a creative, experienced and talented lighting designer (Boyce, 2013).

3 DAYLIGHT, BUILDING INFORMATION MODELLING & HOLISTIC DESIGN

In the UK and Ireland, as well as many other parts of the world, the foremost authority on interior lighting is the Society of Light and Lighting (SLL), previously named the Illuminating Engineers Society and founded in 1911 (Loe et al, 2009). It has set guidance for the industry since 1936 and writes a wide variety of design guides for the lighting sector, which are widely adopted throughout Europe and other parts of the world. The SLL's Code for Lighting and accompanying Lighting Handbook provide a summary of lighting standards and offer further qualitative guidance, which combines to provide a comprehensive text on lighting. In recent years, the European Committee for Standardization (CEN) has also set standards for all countries in Europe. Although there are many standards, in the foreground are EN 12464 Lighting for Workplaces and EN 15193 the Energy Performance of Buildings Directive. In EN 12464 minimum requirements for lighting are laid down for both interior (part 1) and exterior (part 2) lighting. EN 12464 specifies many quantitative criteria, but the most prominent are maintained illuminance, uniformity, color rendering index and unified glare rating (CEN, 2011a).

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People *love* daylight and spaces that make extensive use of it are generally considered attractive, but they do not *love* it unconditionally (Veitch and Galasiu, 2006)(Al Marwaee and Carter, 2006). Like many other light sources, daylight has to be controlled to avoid visual discomfort as well as thermal discomfort. Provided this is done, then daylighting through windows can create a bright and interesting visual environment, these are the dimensions by which people assess the quality of a space (Boyce, 2003). Variation of daylight throughout the day delivers meaningful information about the passage of time and the view out can provide useful stimulation (Boyce, 2003). Buildings where daylight is thoughtfully distributed without visual or thermal discomfort are considered better buildings (Veitch and Galasiu, 2006). Maximizing daylight and minimizing energy used by electric lighting must take place in a way that minimizes overall energy consumption from the building. It is unacceptable to maximize daylight to reduce light energy if thermal energy requirements increase due to the need for extra heating or cooling. It should be remembered that extra glazing would increase heating load in winter and cooling load in summer, whilst electric lighting can also contribute significantly to building cooling load requirements. So this is a complicated balance, which varies with building type, construction, orientation, usage and location.

It is generally agreed in the UK and Ireland that the way to address this challenge is to use a holistic design approach; integrating the design of the architecture, glazing and engineering design. Input is needed by the architect, structural engineer, heating and ventilation engineer, electrical engineer, lighting designer, interior designer and control systems engineer. Modern building information modeling (BIM) software facilitates such multi-disciplinary interaction and its use is growing exponentially in construction projects in this part of the world. Adopting BIM for construction projects is considered similar to adopting e-mail when it first became freely available, in that businesses that do not adapt will be left behind. BIM allows lighting designers interact with the design team when early architectural decisions are made to provide input to decisions about building size, shape, construction type, orientation and glazing. The role of the heating and ventilation engineer is also crucial at this time so that potential solar gains can also be estimated for these variables. BIM software facilitates design changes and orientation variation in a cross-disciplinary way to optimize design, maximize customer and user satisfaction whilst minimizing energy and other costs for the building.

4 LIGHT EMITTING DIODES

For people reading commercial lighting publications or attending trade shows, it would seem that there is a single solution for all lighting problems – LEDs. It is suggested (Boyce, 2013b) that the growth of LEDs has happened for three reasons. The first is the immense quantity of money invested in LED by organizations and the consequent rapid development in their capabilities. The second has been the enthusiasm of regulators who see LEDs as the ultimate replacement for incandescent. The third is fashion. At present, opting for LEDs is considered progressive and enlightened. The outcome of these factors has been explosive growth in the LED market, and similar to all such markets, it has attracted many suppliers. Some of these have a reputation to uphold, but many do not. As a result, the market is now saturated with LED products of unknown pedigree. This raises an issue for designers, specifiers and purchasers; how can they distinguish good equipment from bad? Surely lighting research can provide this answer? Sadly, it can’t. As a result, very little guidance is available for the purchaser when selecting LED equipment (LILG, 2012). Boyce has suggested (Boyce, 2013b) that a valuable contribution to the lighting community would be a set of standard, simple questions to ask the LED supplier. Any supplier that is unwilling, or unable, to answer these questions should be treated with caution.

These questions would address some of the major issues associated with LED products. Traditionally, not many standards have been in place to regulate the construction, manufacture, performance and operation of LEDs, but in recent years, this has improved somewhat with the introduction of ‘IESNA LM-79-08, IES Approved Method for the Electrical and Photometric Measurement of Solid-State Lighting Products’ (IESNA, 2009a) and ‘IESNA LM-80-08, IES approved Method: Measuring Lumen Maintenance of Light Emitting Diode Light Sources’ (IESNA, 2009b). Both of these test methods allow manufacturers to have their products tested in an independent laboratory, to a standard set of testing procedures. This offers designers, purchasers and specifiers a fair comparison between products. Now that this standard set of test procedures is available, the International Electrotechnical Commission (IEC) has gone one step further and published a Publically Available Standard (PAS) ‘IEC/PAS 62722 Performance requirements – LED luminaires for general lighting (IEC, 2012). This document suggests the quality criteria that should be used when comparing LED products and also suggests that this information should be published on product datasheets. The criteria listed include; input power, luminaire luminous flux, luminaire efficacy, luminous intensity distribution, photometric code, correlated color temperature (CCT), color rendering index (CRI), rated chromaticity co-ordinate values both initial and maintained, lumen maintenance code, rated life in hours of the LED module and the associated lumen maintenance (Lx), failure fraction (Fx), corresponding to the rated life of the LED module in the luminaire, ambient temperature (Tq) for a luminaire. Of these, newest and most important to designers and specifiers are chromaticity issues and how the life of an LED product is stated. LEDs have the potential to exhibit extremely long lifetimes and for that reason, LM-80-08 tests luminaires only until 6,000 hours of operation (IESNA, 2009b). Once the fitting has been tested for 6,000 hours, ‘IESNA TM-21-11, IES Approved Method: Making Useful LED Lifetime Projections’ is used to extrapolate these measurements and estimate useful life of the LED product (IESNA, 2009c). LED lifetime is then specified in terms of parametric and catastrophic failure, to a chosen time. An example would be 50,000 hours to L70F10. This would mean that after 50,000 hours of operation, this luminaire will emit

70% of its initial light output and 10% of the individual LEDs within will have failed, thus meaning that the luminaire is at the end of its useful life. Again, this offers designers and specifiers the opportunity to compare LED product lifetimes on a fair basis. Chromaticity coordinates are recorded initially and every 1,000 hours until completion of testing. These results will give designers and specifiers realistic information about how the color appearance of the tested LED products will vary initially and also how it will vary during the life of the product. Insisting that these test results are produced and spending time to fully understand what the results are portraying will go a long way to ensuring better quality LED products are specified and installed (CELMA, 2012), which should dispel some of the tales and skepticism that surrounds poor quality LED installations that have undoubtedly have taken place over the number of years.

If we now have an idea how to differentiate good quality LED products from bad quality LED products, where are they applicable? Solid-state technology is developing at an amazing pace and recent developments have seen LED efficacies equal that of fluorescent T5 lamps. Add to this, that once light loss factors such as diffusers and louvers are considered, LED can be almost 20% more efficient. But *good quality* LED products are expensive, approximately two and a half to three times the equivalent T5 fluorescent fitting, giving an eight to twelve year payback period in most cases. This, amongst other factors, leaves linear fluorescent lighting the prime choice for general lighting solutions the near future. Areas within general lighting where LED is financially viable at present include; architectural lighting, replacements for halogen lamps, replacements for compact fluorescent downlights and replacements for external metal halide fittings, particularly the lower Wattage (<70W) fittings.

5 LIGHTING CONTROLS

EN 15193 the Energy Performance of Buildings Directive details a method of estimating lighting energy consumption that delves beyond maximum installed loads. The method is called LENI, the Lighting Energy Numeric Indicator (CEN, 2006). LENI is a measure of the total lighting energy consumption for a given space for an entire year, divided by the area of that space. It is recorded in kWh/m^2 per annum and gives a much more realistic indication of energy consumed by a lighting installation (CEN, 2006).

Over the past decade, automated lighting controls have become common place in building engineering. However, they are not without problems. Ensuring user satisfaction throughout the working day requires integration of the lighting control system in an acceptable way to ensure lights are on when needed and off or dimmed when appropriate. Gradual dimming is often preferred by users as opposed to sudden switching off (Veitch and Galasiu, 2006)(Newsham et al, 2008), which can be distracting for people using the space. Dimming without override facilities often results in user dissatisfaction (Veitch and Galasiu, 2006)(Newsham et al, 2008). Various studies have shown that there can be much user dissatisfaction with poorly operated control systems.

For the future, however, it may become normal for individuals to have control of their own lighting. Technology is already moving in this direction. LED luminaires are already easily dimmed and can change spectrum and light distribution on demand. Developments in wireless communication and computing power are making it possible for a regular array of luminaires to be adjusted to provide occupants with their preferred illuminances at minimum electricity consumption, and doing this without moving luminaires when workstations are moved (Wen and Agogino, 2011). Boyce suggests that with these developments, the concept of plug and play lighting can’t be far away (Boyce, 2013). But will this cause chaos, or will it be an improved solution comparable to automated controls? There is already evidence to suggest that giving individuals control improves occupant satisfaction. People prefer varying illuminances for the same task (Maniccia et al, 1999)(Newsham et al, 2003)(Newsham and Veitch, 2003)(Boyce et al, 2006a)(Boyce et al, 2006b) . This means that for any chosen, automatically fixed illuminance, only a minority of occupants will experience their preferred condition. When users have their desired lighting conditions, this results in improved mood and improved judgments of environmental satisfaction (Newsham et al, 2003)(Newsham et al, 2004). Additionally, improvements in mood, lighting satisfaction, and discomfort achieved by giving people individual control of their lighting are proportional to the difference between the fixed illuminance and the preferred illuminance (Galasiu et al, 2007). An extensive field study (Veitch et al, 2010) has also shown that direct / indirect lighting suspended over each workstation and providing individual control is considered better than uniform lighting with simple switching and it saves energy.

6 CONCLUSION

To sum up, this is an exciting and challenging time for the lighting industry. We are challenged to provide robust solutions that maximize the benefits of new technologies whilst protecting our clients from poor quality products and installations. We must maximize light quality and minimize energy use by integrating daylight with appropriate artificial light in a way that lifts the spirit of those using the space and enable them to operate and override automatic lighting controls when required. We also have to ensure the reliability of products we specify and this is particularly challenging when technology is evolving so quickly.

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Energy and water use patterns in Portuguese secondary schools – main relationships. Seven schools case study analysis.

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ABSTRACT: Resources use, namely energy and water, have a major impact on buildings life cycle sustainability. Moreover they account for a high percentage of running costs, especially in service buildings, such as schools. On the other hand, the project phase is an important window of opportunity to impact use phase. This paper discusses the importance of data from buildings in use to inform the project phase and enhance buildings sustainability through resources use efficiency and/or reduction. A brief review of a case study analysis on seven Portuguese secondary schools energy and water consumption is presented. The main goal is to search for patterns on resources use in buildings and meaningful impact factors, integrating quantitative and qualitative research tools.

1 INTRODUCTION

1.1 *School buildings and sustainable development*

Promoting best practices in resources use in school buildings has a double goal: the reduction of inefficiencies in resources consumption, and consequent gas emissions, of a vast net of public buildings and the opportunity to raise awareness among youths, promoting a more responsible use and management of buildings in the future, as behaviours and knowledge obtained at school can be applied and disseminated in other contexts. Agenda 21 had stated education as being critical for promoting sustainable development. The reviews of 2006 and 2009 EU Sustainable Development Strategy maintained education as a critical aspect of sustainable development. Moreover, energy use in school buildings has a determining paper in thermal and visual comfort for users (Santamouris *et al*, 2007).

1.2 *Post-occupancy evaluation*

Considering use and users as determining factors for understanding energy, and more generally resources use in buildings, and consequently to promote more sustainable buildings, implies that building designers need to approach reality, study it, communicate with it and analyse data collected from real use to inform the project, in a feed-back continuous process. Moreover, a designer-user interaction allows for a bi-directional exchange of information, which, in the present research, emerges as a relevant condition for buildings' sustainability. According to Zimring (2002) post-occupation evaluation (POE) is a methodology of approaching the reality of buildings in use, to better understand and draw conclusions with prominently practical goals. These goals can be multidimensional and include feed-back on designers for future project developments, inefficiencies and problem detection and solving, inform policies and building codes and enhance their applicability. Thought POE methodology was not primarily focused on buildings sustainability goals, and did not cover an environmental dimension, an extension of its scope is proposed. From the factors, presented by Rati *et al* (2005) as the main factors impacting buildings energy performance – climate, urban context, building, systems and occupants - occupants are the less studied factor and potentially the more complex to address. Occupants are a key element to understand energy use in buildings, not only per si but also because of their interaction with other factors. A deeper understating of occupants and their interaction with buildings is defended as a mandatory step to achieve a more sustainable built environment (Accame et al, 2012).

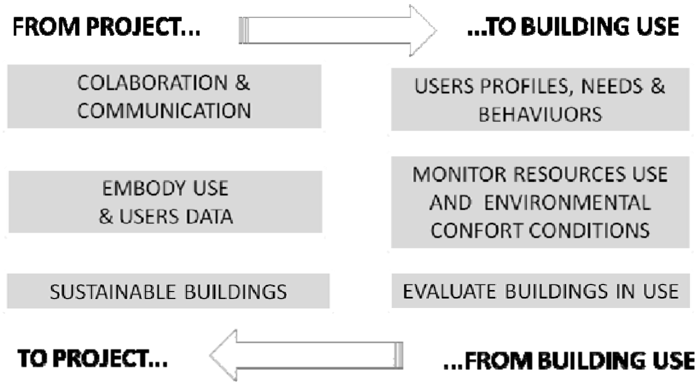


Figure 1. Simplified POE proposed concept

1.3 *Portuguese secondary school buildings modernization program (PMEES) and energy use*

After an expansion period, during the 80's and early 90's of the XX century, the Portuguese government launched, in 2007, a program to refurbish and modernize 332 from the 587 secondary public schools (PMPEES). A year earlier, in 2006, Portugal adapted the European Union directives on buildings energy efficiency and air quality certification EPBD (Energy Performance of Buildings Directive). PMPEES was therefore the first major public investment on buildings refurbishment adopting the new legislation and requirements on energy use in buildings. Parque Escolar (the Portuguese entity responsible for the modernization of secondary schools program), started monitoring resources use in the refurbished secondary schools. Because awareness about resources use in buildings and the valuing of such information is still low in Portugal, mechanism for monitoring resources use and collecting data are not yet implemented in Portuguese schools. Therefore, only data regarding electricity use is available and being monitored in a continuous away.

In 2008, the total electricity consumption in 90 secondary schools was of 18.416MWh and in 2010, after the refurbishment program, the same sample consume was of 26.400MWh. Although the raise was expected - as indoor comfort regulations were not being met before the refurbishment and the programme included an increment in technological teaching tools - close attention should be pay to resources use patterns in schools, in order to monitor the impact of the modernization process and present legislation.

What are the main factors impacting energy and water use in school buildings? Identifying these key factors will allow feeding improvement processes and a "lessons-learned" database regarding resources use efficiency for future school buildings construction or refurbishment, as proposed in the recast EPDB: "implementation and lessons learned".

2 METHODOLOGY

In order to achieve the main objectives of the research, the main methodological steps were: the case studies selection, interviews with school directors, walkthrough visits, data collecting, statistical analysis on energy and water use, qualitative analysis of interviews and walkthroughs data. The data regarding energy and water use was collected considering five consecutive use years, comprising consumptions between 2008 and 2012; before, during and after the modernization program (PMEES). Pressure on resources during construction phase (2009 and 2010) was therefore also verified. A multivariate statistical analysis comprehending selected variables was performed in order to identify possible behaviour patterns and meaningful impact factors on the resources use. As a measure to relate variables, Pearson's correlation factors were calculated. A 95% interval of confidence was considered. Considering the present number of cases, results were considered significant after 0.60, according to Price (2000). Significant values in correlation tables appear marked with (*).

The interview was semi-structured (Guerra, 2008) and followed a content scheme divided in four mains parts: (1) School data and general information, (2) Energy and water data, use and management in the school, (3) Impact of the modernization process in the school, and (4) School awareness and involvement in environmental sustainability issues and projects. Visits to schools were accompanied by the directors or by a member of the operational staff. Preliminary visits took place during the holidays, in August 2012, and following visits occurred during the opening period, both during the day and during the night period, in 2012 and 2013.

2.1 *Cases studies selection*

Schools were selected considering homogenous climatic and geographical features – all schools are located in the metropolitan Lisbon area - but heterogeneous behaviour regarding the resources use. From a sample of 20 schools, located in the Lisbon area and refurbished by 2010, seven schools were selected to seek for diversity regarding electricity use, a previously known variable. Table 1 presents some information about the seven schools selected and energy and water use.

Table 1**.** Energy and water use and associated activities in eight secondary schools

School	Building type	Water		Electricity		Gas		Solar panels		Photo vol-taic panels	GTC
		Public network	Other source	cooling and ven-tilation	heating	water heat-ing	space heat-ing	showers water heating	kitchen water heating		
DPV	Pavilion	x		x		x	x	x			x
EQ	Pavilion	x		x	x	x			x		x
JO	JCETS	x		x		x	x	x	x		
JS	Pavilion	x		x	x	x		x			x (**)
PA	Pavilion	x	x	x	x	x			x		x
PM	Historic	x		x		x	x	x	x	x	x
SS	JCETS	x	x	x	x	x		x	x		

2.2 *Variables selection*

For the identification of potentially relevant normalization factors, the uses of different resources were considered dependable variables and were compared among themselves and with independent selected variables. These were grouped as being associated with the physical features of the building – "building variables" and as being associated with occupation,"use variables" (Tables 2 and 3). For "daily frequent users" the total number of students, teachers, operational and administrative staff was considered. School schedules are locally decided, with some schools opening at night and on weekends, so "opening hours" was also considered a potentially relevant factor.

Table 2. Dependent variables (resources) and Building variables

Resources	Unit	Data source	Building variables	Unit	Data source
Electricity	kWh	Energy and water bills from 2008 to 2012	Total building area	m^2	Modernization projects
Gas	kWh		Deployment area		
Water	m^3		Pavement area		
			Total site area		
			Green areas		
			Building volume	m^3	
			Classroom average volume		

Table 3. Use variables

Use variables	Unit	Data source
Daily frequent users	Average number of people per day / per year	School administrative services
Students	Average number of people per day / per year	
Opening hours	Total hours per year	
Meals cooked in school	Total of meals prepared in the school canteen during 2012	

3 CASE STUDY ANALYSIS

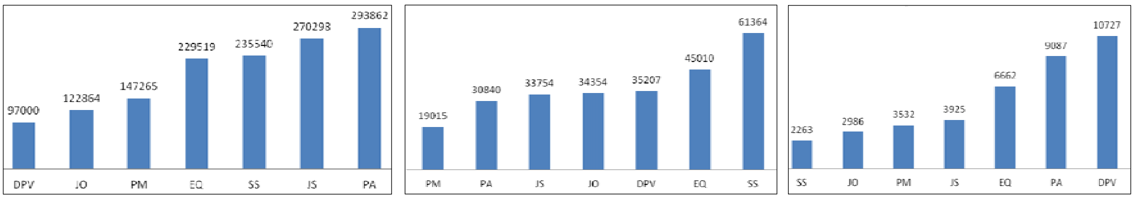
3.1 *Statistical data analysis – electricity, gas and water use in seven secondary schools*

Table 4 presents the total energy (kWh) and water use (m^3) for 2008 and 2012, and the average normalized consumption for the seven schools. Because the refurbishment introduced a new activity to gas use in some schools – space heating – this resource has the highest increase. Considering that the electricity sector in Portugal has a relevant renewable source production, the increase in gas use in the schools is affecting negatively its sustainability, especially considering that this resource extraction and transport has a strong impact for environment. Electricity use in the seven schools also increased, mostly due to the upgrade of comfort and legal requirements regarding lighting, ventilation and safety, but also related to the increase of technological teaching tools. Water use has decreased, even though the number of students and building area has increased for all the schools, 135% and 141% in average, respectively. Equipments and system inefficiencies were most likely to be impacting significantly water use in the schools before the refurbishment.

Table 4. Energy (kWh) and water use (m^3) before and after the refurbishment programme.

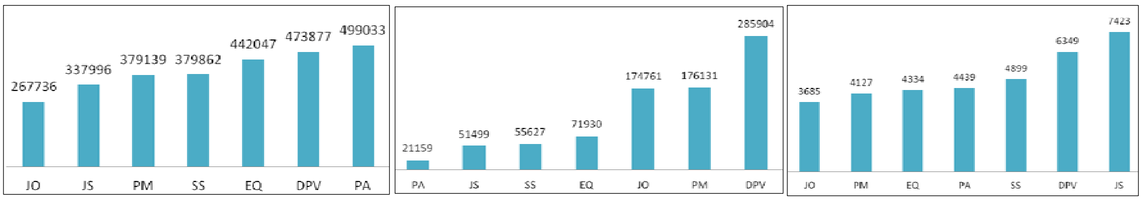
	Electricity		Gas		Total energy		Water	
	total (kWh)	average (kWh/m^2)	total (kWh)	average (kWh/m^2)	total (kWh)	average (kWh/m^2)	total m^3	Average (m^3/user)
2008	1.396.348	35	259.545	6	1.655.893	41	41.190	4
2012	2.779.690	49	837.011	16	3.616.701	65	37.267	3

A decrease in the variation of resources use among the schools, between 2008 and 2012, is registered in electricity and water use, but also in gas, if considering only gas associated with hot water, which corresponds to the only activity associated with gas use before the refurbishment (Fig. 2-3). A more regular behaviour seems to be related with electricity use, as the use of this resource presents the lower variations, both before and after the refurbishment.



Electricity variation in 2008: 2,79x Gas variation in 2008: 3,23x Water variation in 2008: 4,74x

Figure 2. Electricity, gas and water use in seven schools in 2008.



Electricity variation in 2012: 1.86x Gas variation in 2012: 3.4x (heating systems) 1.64x (hot water) Water variation in 2012: 2.014x

Figure 3. Electricity, gas and water use in seven schools for 2012.

In order to understand if there was a correlation between the three resources use in the five years, Pearson's correlation factors were calculated. This also revealed that electricity is the most regular, and therefore potentially predictable, resource use. Table 5 presents only the values obtained for electricity, as gas and water didn't reveal a significant statistical correlation along the years analysed. Electricity use along different years seems to be correlated especially in subsequent ones. The relation is weakened during the years related to the construction phase. Tables 6 and 7 analyse, respectively, potential correlations between the three resources in "regular use years" (2008 and 2012) and during the refurbishment (2009 and 2010). The use of the three resources is moderately correlated during the refurbishment years (2009 and 2010), which indicates that this activity introduced pressure on all the resources. No significant correlation between the three resources use was established for the schools analysed.

Table 5. Correlation factors for electricity use in different years.

Electricity use	2008	2009	2010	2011	2012
2008	1				
2009	0.94*				
2010	0.29	0.54	1		
2011	0.46	0.6	0.88*	1	
2012	0.62*	0.73*	0.82*	0.96*	1

Table 6. Correlation factors for resources use in two regular use years.

2008	Electricity	Gas	Water	2012	Electricity	Gas	Water
Electricity	1			Electricity	1		
Gas	0.65*	1		Gas	0.18	1	
Water	0.35	0.28	1	Water	0.09	0.05	1

Table 7. Correlation factors for resources use during a refurbishment operation.

2009	Electricity	Gas	Water	2010	Electricity	Gas	Water
Electricity	1			Electricity	1		
Gas	0.19	1		Gas	0.57	1	
Water	0.58	0.64*	1	Water	0.89*	0.63*	1

The correlation analysis between dependable and independent variables (Tables 8-9) supports the conclusion that different factors impact differently the use of the various resources. Very different results were obtained for the correlation of the independent variables with electricity, gas and water. Therefore, using the same normalization factor for different resources use in buildings may lead to significant *bias* in results. Even for the same resource, normalization methodologies should consider the activities associated with each resource. For example, in schools with gas use only for water heating, area or building related variables are not the most suitable for normalization, benchmark or goals settings.

For the selected variables only for electricity use a meaningful and consistent correlation for the five years was obtained (Tables 8-9 refer to 2012 values). Regarding this resource use, variables associated with use and users (daily frequent users, students and opening hours) appear to be more significant than the building variables (pavement area and building volume). Although no value equal or superior to 0.60 was obtained between the selected variables and water and gas use, both this resources relate positively with the variable “opening hours”.

Gas is the resource used in all the schools for meals preparation; however, the correlation between the two variables is weak. In three of the schools it was possible to calculate gas use per activity, as schools have different meters for hot water and space heating. Meals preparation accounts for approximately 4 to 13% of total gas use in these schools, which is concordant with the low impact correlation factor obtained.

Activities potentially related with water and area, such as cleaning, seem to have little relevance for total water use. Green areas and total exterior areas have positive but still weak correlations. When seasonal water use is considered (May to October, the hot season) the correlation factor between water use and green areas increases to 0.52. As there are no partial water use meters in schools, showers use can only be estimated through surveys, to be implemented in a future research phase. This activity is probably one of the main activities pressuring water, but also gas use in schools with electrical space heating systems (when gas is used for space heating, this becomes the most impacting activity).

Table 8. Pearson's correlation factors for resources use and "building variables"

2012	Total building area	Deploy-ment area	Pavement area	Total site area	Green ar-eas	Building volume	Classroom volume
Electricity	0.33	0.44	0.67*	0.44	0.17	0.61*	-0.01
Gas	0.18	0.14	0.02	-0.4	-0.64	-0.02	0.53
Water	-0.11	0.3	0.17	0.55	0.42	0.04	-0.44

Table 9. Pearson's correlation factors for resources use and "use variables"

2012	Daily frequent users	Students	Opening hours	Meals preparation
Electricity	0.81*	0.72*	0.82*	-0.61
Gas	0.01	-0.23	0.24	0.19
Water	0.45	0.34	0.57	0.03

4 RESULTS AND DISCUSSION

4.1 *Results - quantitative data analysis*

There is not a statistically meaningful relationship between electricity, water and gas use in the schools during current use years, indicating independency between the resources use and also that different factors are impacting each resource. Hens et al (2010) correlated environmental management and environmental performance in 25 primary schools in South Africa. Correlation between energy and water use results was also low.

Different variables should be considered when normalizing data related with electricity, gas and water use in service buildings. The choice of normalization variables for data analysis and benchmark that do not take into consideration the specificity of the building functional use can be a cause for less feasible analysis and conclusions.

Use variables, related to specific functional features such as opening hours should be considered when benchmarking and comparing electricity use in service buildings. Similar conclusion can be found in Accame et al (2012) or Buvik & Rynska (2007). Moreover this variable (opening hours) is the one that relates positively, and more consistently, with the three resources.

Electricity use is more significantly correlated both with building and use variables than gas and water use, the first presenting more homogenous patterns and the others more heterogeneous behaviours.

Regarding energy, electricity accounts for the highest percentage of total energy use, before and after the refurbishment, however, the increase in total gas use between 2008 and 2010 is of 322% (electricity total use raised 199%). The use of HVAC systems and temperature and ventilation comfort conditions are activities pressuring resources use in school buildings (Santamouris et al, 2007), in a tendency similar to the verified the 1980's and 1990' in office buildings (Guedes, 2000). In some contexts gas is the resource with the highest impact in total energy use in school buildings; Dimoudi & Kostarela (2009) collected data on nine school buildings energy use in Greece in 2004, where the mean energy use was 123,31kWh/m^2, from which 109kWh/m^2 referred to gas, Santamouris et al (2007) collected data regarding 320 schools in Greece with a mean total energy use of 95kWh/m^2, from which 68kWh/m^2 related to heating. As the authors underline, benchmarks and rating schemes should only be based on nationals building stocks. Nevertheless, the average energy use in the seven Portuguese secondary schools (Table 4) highlights our geographical, climatic, and yet cultural beneficial features for implementing passive strategies. No data or similar studies were found on water use in school buildings.

4.2 *Results - qualitative data analysis*

Interviews and visits main conclusions summarized in this paper relate to the user's points of view and also to behavioural and organizational aspects considered potentially related with energy and water use in the schools.

i. Valuing information and communication:

Energy and water consumption data is not strongly valued in schools and is not monitored and collected in a continued and current process. All directors revealed that they did not have a consistent knowledge on the schools energy and water consumption and none on benchmarks and data regarding other schools or similar building types. In some cases there wasn't a full knowledge of the systems and resources used in schools, nor on the equipments location. Lack of knowledge for operating systems and equipments, mainly HVAC systems and GTC's was mentioned in the interviews and confirmed by operational staff during visits. Inefficient maintenance in school buildings was also related with low levels of manager's knowledge about the building and equipment features in França & Ornestein research (2010) and with energy use in Accame et al (2012).

ii. Usability, operability and accessibility of systems and construction elements:

The schools have different tools to manage the systems. Some GTC's manage HVAC systems, while others manage both HVAC and lighting systems, while in some cases there is only a manual control. Having GTC systems doesn't necessary means more efficiency and comfort. Sustainability and efficiency principles and acknowledgment of users needs (considering different users profiles) seems to emerge as a relevant combination for best practices in energy use and managing the GTC system. Windows and shading devices usability and accessibility is another factor that seems to be strongly motivating a more or less intensive use of passive strategies. Users also privilege the possibility of choosing between passive and active strategies for establishing indoor comfort conditions, although the modernization projects considered only mechanical systems to fulfill regulation standards. Accame et al (2012) refers to this as allowing *hybrid controls*;

iii. Functional organization and space occupation:

Only in one interview principles of energy efficiency were referred as a factor considered in the classes distribution. This school has the second lowest energy total use in 2012 (Fig. 2) and one of the higher number of users and operating periods. Visits to schools during all the functional period – including night - allowed acknowledging that the school that concentrated night activities in smaller areas also presented lower values for electricity use, while schools that spread a small number of users throughout larger areas during night classes presented the higher consumption values. One of the main constraints for night classes' location is the technological classrooms, mostly used in professional courses, taught mostly at night. The cases with higher and lower energy use also correspond to the schools where this classrooms dist longer and closer to entrance and common use areas. Buvik & Rynska (2007) also refer to space efficiency as a main factor impacting energy use in school buildings.

Green areas valuing and management:

Valuing green areas as a pedagogical tool is increasing the pressure on water demand. Visits to schools showed that more than green areas' size, it is the users' functional and pedagogical valuing of such areas that increases pressure on water demand, as some of them are abandoned while others are maintained and used for pedagogical purposes. Measures to relief the pressure on water for green areas maintenance, that simultaneously allows preserving these areas, should be considered. Taking into account that showering is another activity potentially putting a significant pressure on water demand, this could be an interesting source of grey water, which could be used for green areas maintenance.

4.3 *Discussion of results and next steps*

Case study analysis and bottom-up methodologies area interesting and valid models for approaching reality as a source of information for feed-back on project design strategies and studying energy demand in buildings (Accame et al, 2012). Although the small number of cases that it implies may weaken a quantitative and statistical analysis, combining qualitative and quantitative data collection and analysis allows a deeper and better understanding of buildings' use behaviour patterns. POE evaluation methods should consider full time data collection and observations that allow establishing day-night patterns, as off-peak energy use has a relevant impact on total energy use. Different building typologies have singularities related to its specific use and users. Identifying meaningful variables and factors relating use and resources consumption is a constant challenge for incrementing buildings environmental sustainability. Multivariate statistical analysis allows for a more grounded choice of normalization variables for analyzing energy and water use in buildings. Such methodologies should be adopted when benchmarking and defining milestones for resources use in buildings. More research is needed, regarding especially gas and water use. Because the use of electricity is more homogeneous and patterned, this resource use presents a better potential for predictive models.

4.4 *Main conclusions within the case*

Energy use increased significantly after the schools refurbishment and should be closely monitored with efficiency and potentially reduction goals. The introduction of new equipments and systems in buildings augmented their complexity. Knowledge and valuing sustainability principles seems to be relevant for an efficient and sustainable interaction between building and users. Passive design strategies must ensure equipments and building components accessibility, usability and adaptability in order to achieve its goals. Space organization and layout distribution should consider energy efficiency principles along with functional criteria. Although not often used for benchmarking and energy normalization, opening hours is strongly related with electricity use in the schools. The water supply system renovation allowed for an effective reduction of approximately 10% in water use in the schools, relieving the pressure on this resource.

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Parametric analysis of the energy demand in buildings with Passive House standard

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ABSTRACT: This paper presents the influence of the physical, mechanical and quantitative values of the materials and elements on the energy demands of passive houses and the corresponding emissions of CO_2. The goal of this paper is to present the starting parameters for the design of passive houses, as well as for all kinds of energy efficient buildings. The building orientation and the thickness of the thermal isolation of the building envelope are one of the factors affecting the achievement of the Passive House standard. The analysis of the variations of these two parameters give a clear picture of the impact of each of these two parameters as well as of their combination on the energy needs of the Passive House presented in this paper. The calculations were based on the methods of thermodynamics, using MKS EN and DIN standards, and program packages PHPP 2007, HEAT2 and NOVOLIT. The obtained results will enable comparison of passive houses with existing buildings that will facilitate analysis and estimations of the costs and benefits of the rehabilitation of existing buildings, including feasibility studies.

1 INTRODUCTION

The radical changes in urban development, related to the way the future buildings will be designed and built, will have an essential influence on reducing the energy consumption as one of the most important factors for sustainable development. Globally, the strategy expressed by "energy triad" (Trias energetica 20:20:20) was set and requirements to be met up to 2020 are: 20% reduction of energy consumption, 20% reduction of CO_2 emissions and 20% increase of renewable energy use. Nearly 40% of the total energy consumption in Europe is consumed in buildings, 67% of it in residential buildings and only 33% in commercial buildings. Hence, this paper refers to the analysis of residential buildings under Macedonian climate conditions.

Passive buildings represent the highest standard in the energy efficiency of buildings (Bahr et all. 2012). They guarantee extremely low energy needs, which can be fully meet with relatively small alternative energy sources (sun, water, wind, waste, etc..). It will help to decrease the environmental impact of the building sector, in same time it gives opportunity for full independence from the most exploited sources of energy that are used so far and hence, the concentration of CO_2 in atmosphere could be reduced drastically.

2 BASIC FACTORS FOR ACHIEVING THE PASSIVE HOUSE STANDARD

2.1 *Micro and macro location*

The location is an important factor for calculation of the energy demand of the building, either for heating or cooling, due to the angle at which the sun rays fall on the ground in summer or winter. Shadings over the buildings that are coming from the nearby mountains, hills, buildings, plants, from the structural elements of the building and even from the position of the windows in the wall, have a major influence on energy demands too.

2.2 *Architecture*

The layout of the rooms, the disposition, design and especially the compactness of the façade have a huge influence on energy demands of the buildings and therefore the ratio between the surface of the building envelope and the building volume (A/V) should be approximately 0.7 m^2/m^3.

The south side shall be assigned to the rooms for longer stay (living room, dining room, study room, etc..). The north side shall be assigned to the bedrooms, if the building is at the ground level. If the building has more floors, the bedrooms shall be on the south side. The recommendation for the toilets, staircases, storage rooms and other ancillary facilities is always to be oriented on the north side, or in exceptional situations on east or west. On the south facade windows should occupy 25% to 30% of the area and should have shading blinds or louvers with such an angle that allows the winter sun to shine the windows, but disables the summer sun. The windows on the north side should be reduced to the minimum possible architectural standards. It is essential to avoid windows on the east and west side of the building. If it is still necessary they should be of the smallest possible size and well shaded.

2.3 *Building envelope*

For the walls, roof and ground floor the thermal insulation thickness should satisfy the requirement $U \leq 0.15$ W/(m^2K). It is commonly achieved by the insulation thickness of 250 mm, 300 mm, up to 400 mm, depending on climate conditions. Glazing is mostly with three-layer low emission glass with $U \leq 0.80$ W/(m^2K), but for the build in windows the U-factor has to be $U \leq 0.85$ W/(m^2K). The general light transmittance (solar factor) has to be $g \geq 50\%$. Nowadays, we have glazing with $U = 0.51$ W/(m^2K) and $g \geq 62$. The same criteria are applicable to the doors. For the entrance doors the certificate for the highest climate test E (extreme) is required and the U factor has to fit the value $U \leq 0.80$ W/(m^2K). In case of Passive House the heat losses through thermal bridges are strictly limited to total $U \leq 0.01$ W/(m^2K).

2.4 *Air impermeability*

Air impermeability is one of the criteria for evaluation and certification of passive houses and limit value is $n_{50} \leq 0.6$ h^{-1}, where n_{50} is the ratio between the volume of the scavenging air at a pressure of 50 Pa and the total volume of the building. It is recommended this value to be reduced as much as possible, even under 0.3 h^{-1}. The air impermeability is measured through the air exchange with 50 Pa difference in pressure.

2.5 *Ventilation*

Replacement of the used with fresh air and delivery of the required amount of heat to the building are made by the ventilation. Thus, humidity and air quality are controlled. The amount of fresh air needed for passive houses is only 20 to 30 m^3/person which shall be taken into account while sizing of the system for ventilation. For gyms or rooms for smoking the required quantity is 50 to 60 m^3/person. The criteria that the ventilation system shall meet are the following: recuperator with thermal efficiency $\eta \geq 75\%$, high efficiency of fans and controller (CRC $\leq$ 0.45 Wh/m^3); air temperature after the recuperator $\geq$ 16.5°C at -10°C, normal operation of the system up to -15°C, high quality air filters (F7 minimum standard for entry, G4 for output); air speed in ducts $\leq$ 2m/sec.

2.6 *Heating*

An extremely low energy demand for heating enables the heat to be delivered through the ventilation system. The air is heated with electric heaters after the recuperator, or with thermal pumps. When the air is heated by the the sanitary hot water the most economical solutions are obtained. The required energy for hot sanitary water is dominant in the total energy demand and reaches up to 35 kWh/(m^2a), therefore it is an important factor in choosing the right heating system for hot sanitary water.

2.7 *Frequency of overheating*

The frequency of overheating during summer period is an important criterion in the evaluation of passive houses and the value should not be more than 10% of the period in use. Projected summer temperature in the building is 25°C, and frequency of overheating is acceptable only up to 26°C.

2.8 *Additional energy for heating*

The additional energy required for heating is another assessment criteria for certification of the Passive Houses and must not exceed 15 kWh/(m^2a). Distribution of the energy losses and gains and the additional energy requirements are presented in Figure 1.

2.9 *Gross energy requirement*

The gross energy requirement, or so-called initial energy, is one of the assessment criteria for passive houses. The maximum allowable total energy consumption for passive house is 120 kWh/(m^2a).

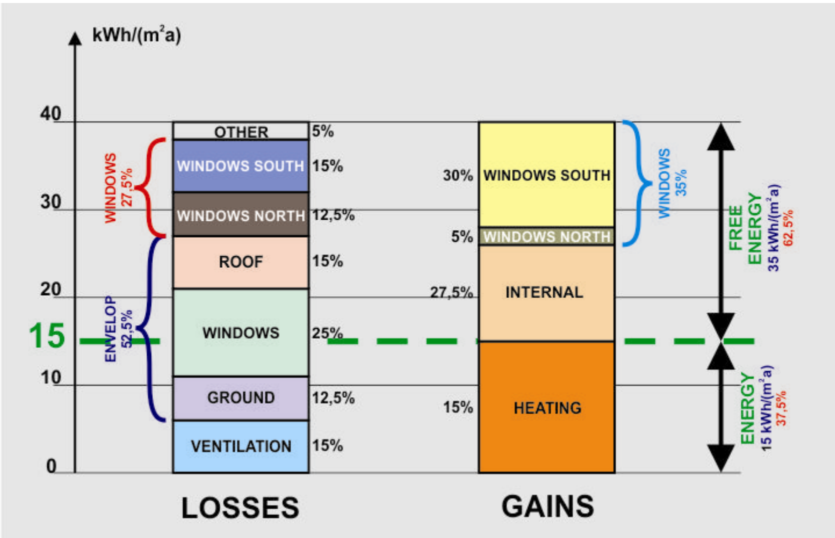

Figure 1. Energy balance in passive house.

3 CALCULATION METHODOLOGY

Appropriate planning, anticipation of all the steps and taking into account the exact entry parameters is an extremely important during the design and the calculation procedure of the passive houses. The entry data that has to be defined as first are: type and purpose of the building; internal design temperature (20°C); number of inhabitants; calculation method (monthly or annual method); location (climate conditions); existence of surrounding buildings (Feist, 1993). The next step is determination of: areas and their functions; U-values of the different parts of the building envelope; emission balances, thermal bridges; as well as energy demands for heating and cooling (Bisanz, 1999).

The basic assessment criteria whether the building meets the standard “passive house” or not, are as follows: specific energy demands for heating/cooling (QSH/QSC) [≤ 15kWh/(m^2a)], or alternative: heating/cooling load (HL)/(CL) [≤ 10W/m^2]; air impermeability [$\eta_{50} \leq 0.6$ h^{-1}]; specific primary energy demand (QSP) [≤ 120 kWh/(m^2a)] (Feist, 1994).

In addition to these basic criteria, there are several criteria which are also important, especially from the economical aspect and the exploitation costs of the building, such as: frequency of overheating of the building (hφ) [≤ 10%]; the ability of the ventilation system to distribute the required quantity of heat (PH) and the emission of CO_2.

This paper deals with the influence of some of the basic parameters on the evaluation criteria for Passive House standard. The orientation of the passive house and the thickness of the thermal insulation of the roof, ground and in façade walls were varied and the influence of these four parameters was analyzed.

In order to obtain complete analysis there is a need to track and vary some more parameters, as: percentage and position of the glazed surfaces on the facade; the type of the window glass; the type of the window frames; the position of the windows in the wall; shading from structural elements; an additional shading in summer; the size and number of solar panels for hot water; the technical solutions for the use of sanitary hot water. All these parameters were subject of the complete research (Andreev, 2013), but the results are not presented in this paper.

The calculations are based on the methods of thermodynamics, using Macedonian MKS EN and DIN standards, and program packages PHPP 2007, HEAT2 and NOVOLIT.

3.1 *Basic data on the analyzed passive house*

The macro location of the analyzed passive house was taken to be in the eastern part of Macedonia. It was located on plateau, at altitude of 600 m. The front facade of the building was completely orientated on south, and the entrance was on the north side. The architecture was taken to be the same as for the famous house of Franz Freundorfer (Figure 2). The building was located in "ideal" conditions in order to enable variations of all mentioned parameters and additionally to enable parametric analysis. The building consisted of ground-floor, first floor and under roof space. The ground floor was allocated to daily living, while the first floor was designed for sleeping and resting. The under roof space was designed to accommodate technical equipment.

Figure 2. Passive house designed by Franz Freundorfer

The construction materials used in this study were different from the ones in the original building because they were adapted to the construction market in Macedonia. Façade walls were the same on all four sides of the building with a thickness of 50 cm and the composition was: plasterboard 12.5 mm on metal sub-construction; rock wool 50 mm with λ = 0.045 W/(mK), gypsum mortar 17 mm with λ = 0.510 W/(mK), masonry blocks from "Ytong" 250 mm with λ = 0.16 W/(mK), gypsum-lime mortar 17 mm with λ = 0.70 W/(mK), 5 mm glue for thermal insulation, 150 mm styrofoam as thermal insulation with λ = 0.024 W/(mK), 5mm glue and smoothing mass, 3mm final mortar.

The gable roof was made of reinforced concrete slab MB30 with shelters on all four sides of the building. The composition of the roof was: 12.5 mm plasterboard on metal sub construction; 50 mm rock wool with λ = 0.045 W/(mK), 100 mm reinforced concrete slab MB30 with λ = 2.30 W/(mK), 150 mm thermal insulation with λ = 0.024 W/(mK), 22 mm wooden revetment with λ = 0.024 W/(mK); 3mm vapor barrier, two layers of wood laths and roof tiles.

The ground floor was placed directly on earth and around the building a route horizontal intermediate plate from extruded polystyrene was set. The composition of the floor was: floating floor base 30 mm, rock wool 20 mm with λ=0.038 W/(mK), 350 mm reinforced concrete slab MB30 with λ = 2.3 W/(mK), 340 mm thermal insulation with λ = 0.038 W/(mK), 8 mm waterproofing layer with λ = 1.2 W/(mK), concrete foundation 100 mm.

The windows were selected from the list of certified passive house windows, as follows:

- Frame W Internorm - passiv Fixverglasung - with distancer 'Thermix',
- Glass INTERPANE - iplus 3E (4:/14/4/14/:4 Argon 90%)

During the process of defining the parameters, the following values and information were defined, too: thermal envelope (line of balance); Treated Floor Area- TFA.

The calculation of the areas covered: all net living areas with heights over 2m, areas with heights from 1m to 2 m were calculated with 50%, non leaving areas (basement, machine rooms and storage) with height above 2 m, were calculated with 60%.

4 ANALYSIS OF THE CALCULATION RESULTS

The calculation of the passive house was made with the software package PHPP 2007. Dimensions of the insulation, windows and all other elements were defined to meet the criteria for a passive house and in same time to be as close as possible to the limit values for the Passive House (PH) standard. In such a way by variations of the above mentioned parameters the influence of each parameter on achievement the Passive House standard could be defined.

The indoor temperature in summer was taken to be 25^0C while in winter to be 20^0C. According to the calculation results the ventilation system could not deliver the needed quantity of heat, so there was a need somewhere in the house a supplementary heating device to be placed. This device should supply an additional 171 W. During the summer period there was no need of cooling system, but opening of the windows was required at nights. Emission of carbon dioxide caused by the heating was 9 kg/(m^{2}a), while the emission caused by the total consumed energy was 19 kg/(m^{2}a). Comparison of the final calculation results with the maximum values defined by the Passive House standard is presented in Table 1.

Table 1. Comparison of calculation results and standard values

Criteria	Symbol	Unites	Design value	Max. value (standard)	Are criteria satisfied?
Specific space heating demand	Q_{SH}	kWh/(m^{2}a)	14	15	Yes
Specific primary energy demand	Q_{SP}	kWh/(m^{2}a)	78	120	Yes
Heating load	HL	W/m^2	10	0	Yes
Cooling load	CL	W/m^2	7	10	Yes
Frequency of overheating	h_ϕ	%	4	10	Yes

4.1 *Influence of the orientation of the building on achievement the PH standard*

The orientation of the building plays an extremely important role in the final balance of energy gains and losses, because windows with south orientation contribute to reduction of the energy demand for heating, while windows on the north side have no contribution to gains, but in opposite - the losses are increased. However, during summer, the southern windows contribute to overheating of the building and hence to energy demands for cooling the building. To prevent overheating there are effective and relatively inexpensive measures for summer shading.

The windows on the east and west sides of the building make significant contribution to the needs for heating of the building in winter, but they are unsuitable for use in the summer because seriously contribute to overheating. The measures for their shading are either extremely expensive or not effective. The orientation of the walls has no impact on energy balance, due to the large thickness of insulation in them.

The influence of orientation of the house, presented in this paper, is based on analysis of several parameters. For that purpose the initial orientation of the house was rotated by steps of 30° clockwise and the results of PHPP 2007 for each of the defined positions of the house are presented in the Table 2.

4.2 *Influence of the thickness of the thermal insulation on achievement the PH standard*

For the purposes of this analysis, the thickness of the insulation in all elements first was increased by 25% from the initial design value until doubling the thickness was reached, and then decreased by 25% until complete elimination of insulation was reached. The results of PHPP

2007 for each variation are sorted and presented in Table 3. The calculations were also made for individual variations, as well as with the same ratio of increase and decrease of the insulation (25%) (facade walls, floor and roof). The results for façade walls are presented in Table 4.

Table 2. Influence of orientation of the building on achievement the Passive House standard

Description	Specific energy demands			Load		Frequency of overheating	CO_2 emision	
	heating	cooling	primary energy	heating	cooling		without equipem.	Total
Symbol	Q_{SH}	Q_{CS}	Q_{SP}	HL	CL	h_ϕ	CO_2^{Qsh}	CO_2^{Qsp}
Unites	kWh/(m²a)			W/m²		%	kg/(m²a)	
Prescribed values	15		120	10	10	10	/	/
Design values	13.93	9.36	77.74	10.06	6.76	3.62	8.88	19.35
Rotation 30°	14.57	11.22	78.33	10.22	7.87	6.11	9.01	19.49
Rotation 60°	16.34	14.93	79.96	10.46	8.56	12.97	9.39	19.86
Rotation 90°	18.26	17.20	81.78	10.65	10.03	11.90	9.80	20.28
Rotation 120°	20.02	16.68	83.47	10.75	8.96	9.89	10.19	20.66
Rotation 150°	21.41	14.99	84.84	10.78	7.55	4.10	10.51	20.97
Rotation 180°	22.92	13.85	86.36	10.94	6.61	1.83	10.85	21.32

Table 3. Influence of thickness of thermal isolation in building envelope on achievement the PH standard

Description	Specific energy demands			Load		Frequency of overheating	CO_2 emision	
	heating	cooling	primary energy	heating	cooling		without equipem.	Total
Symbol	Q_{SH}	Q_{CS}	Q_{SP}	HL	CL	h_ϕ	CO_2^{Qsh}	CO_2^{Qsp}
Unites	kWh/(m²a)			W/m²		%	kg/(m²a)	
Prescribed values	15		120	10	10	10	/	/
Design values	13.93	9.36	77.74	10.06	6.76	3.62	8.88	19.35
No isolation	310.67	0.00	415.63	97.44	0.00	0.00	86.08	96.54
Decreased 75%	57.55	12.27	125.62	24.04	5.13	0.00	19.83	30.29
Decreased 50%	30.27	12.03	95.04	15.58	6.19	0.62	12.84	23.30
Decreased 25%	19.48	10.63	83.43	12.04	6.57	2.15	10.18	20.65
Increased 25%	10.67	8.33	74.56	8.80	6.87	4.54	8.15	18.63
Increased 50%	8.59	7.53	72.62	7.92	6.95	5.20	7.70	18.18
Increased 75%	7.17	6.90	71.35	7.28	7.00	5.81	7.41	17.89
Increased 100%	6.16	6.40	70.47	6.78	7.05	6.96	7.21	17.69

Table 4. Influence of thickness of thermal isolation in facade walls on achievement the PH standard

Description	Specific energy demands			Load		Frequency of overheating	CO_2 emision	
	heating	cooling	primary energy	heating	cooling		without equipement	Total
Symbol	Q_{SH}	Q_{CS}	Q_{SP}	HL	CL	h_ϕ	CO_2^{Qsh}	CO_2^{Qsp}
Unites	kWh/(m²a)			W/m²		%	kg/(m²a)	
Prescribed values	15		120	10	10	10	/	/
Design values	13.93	9.36	77.74	10.06	6.76	3.62	8.88	19.35
No isolation	59.35	16.35	127.71	25.30	6.97	0.53	20.30	30.77
Isolation 50mm	29.91	13.02	94.67	15.70	6.84	1.43	12.75	23.22
Isolation 100mm	20.73	11.21	84.75	12.56	6.79	2.56	10.48	20.95
Isolation 150mm	16.40	10.10	80.24	11.00	6.77	3.21	9.45	19.92
Isolation 250mm	12.35	8.83	76.18	9.44	6.75	3.90	8.52	19.00
Isolation 300mm	11.26	8.44	75.12	9.00	6.74	4.11	8.28	18.75
Isolation 350mm	10.47	8.14	74.36	8.66	6.74	4.27	8.10	18.58
Isolation 400mm	9.86	7.90	73.79	8.40	6.73	4.40	7.97	18.45

The influence of the variation of the thermal insulation thickness on specific energy demand for heating is presented in Figure 3 and the influence of the variation of the thermal insulation thickness on specific primary energy demand is presented in Figure 4.

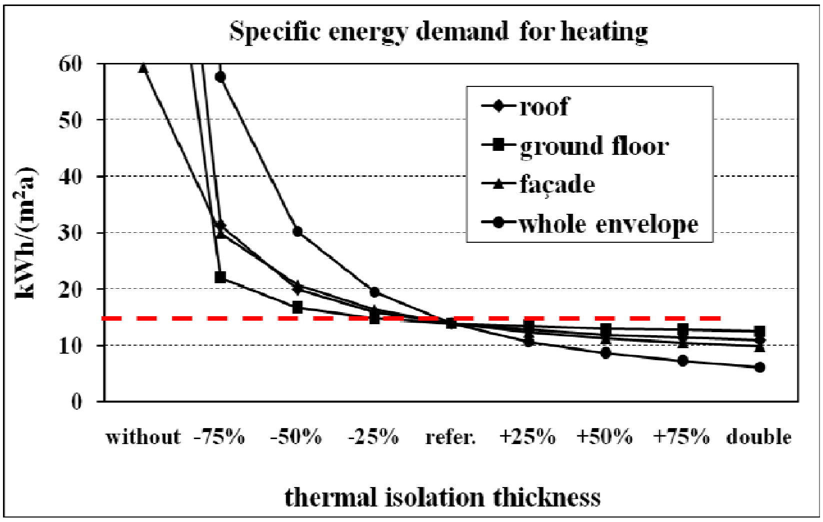

Figure 3. Influence of variation of thermal insulation thickness on specific energy demand for heating

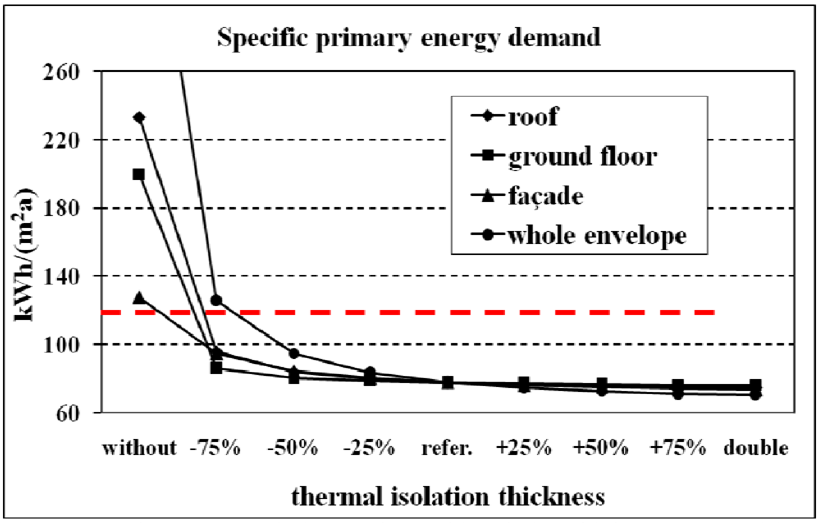

Figure 4. Influence of variation of thermal insulation thickness on specific primary energy demand

5 CONCLUSION

With the radical changes in urban development, i.e in the way the buildings are designed, constructed and renovated, significant impact can be made in the reduction of energy needs and the use of renewable energies, and thus in creating a sustainable future for the buildings and cities. Therefore, it is necessary to prepare special regulations in urban planning where urban blocks will be introduced with passive houses and defining the criteria for successful implementation.

The orientation of the building has direct impact on the energy balance of the passive building. The results show that the building orientation of ± 30° has minimal impact on the demand for energy for heating or the most up to 5%. Further rotation of the building shows far greater impact on energy demand for heating with a growth of about 7% for every additional 30° rotation. The reason for this change is to reduce the exposure of the windows to the southern sun rays, thus reducing solar heat gains.

The orientation of the building has a great impact on energy demand for cooling. The reason for this is the exposure of significant area of windows on the south side to the sun rays, when it is rotated by more than ± 30°. Accordingly, the extended rotation to the north side, i.e. for rotations of more than ± 120° a decrease of energy demand for cooling appears. The rotation of the building to ± 30° from the north-south orientation makes small and insignificant impacts on energy demand for cooling, and thus over the necessary financial means to achieve the Passive House standard. Larger deviations have a serious impact on energy demand for cooling. Good insulation in walls doesn't allow cooling of the building during the night but therefore requires more energy to cool the building.

The orientation itself has a profound effect on overheating the building. Unlike the energy needs for heating and cooling, even the slightest deviation on axis from north-south, the increase in overheating is high. For deviations up to ± 30 °, an increase in the frequency of overheating is even 50%. Maximum frequency of overheating is reached when deviations from the north-south axis are between ± 60 ° and ± 90° and can reach overheating of 2.2 times greater than projected ones. Therefore, it is necessary to apply measures for summer shading on windows (eaves that protect from the summer sun and allow winter sun lighting, various blinds and even deciduous trees).The emission of CO_2 is proportional to the increase in energy consumption for heating / cooling and total primary energy. The CO_2 emissions can vary due to the orientation of the building up to 22% (out of the energy consumed without household appliances) or up to 10% (of total energy consumed).

In order to better understand the influence of the changes in the thickness of the insulation, many combinations have been analyzed in this paper, such as different thickness of the thermal isolation in the roof; to the ground, in the façade walls and in the whole envelope. By analyzing the results it is obvious that the slightest impact on energy demand for heating has insulation in the floor slab, and the most effective is the insulation of the facade. Increasing the thickness of the insulation more than it is recommended (i.e. an increase of the U-value of elements) has no major contribution to the reducing of the energy demands and represents an economically non profitable investment. In opposite, the reduction of the insulation of the elements drastically affects energy demand for heating, so that the least cuts in insulation within any of the building elements will pass the limit 15 kWh/(m^2a). Opposite of the energy demands for heating, the thermal insulation of the building envelope has insignificant impact on energy demand for cooling. The thermal insulation of the building envelope makes almost no impact on energy demand for cooling.

Contrary to expectations, the overheating decreases with decreasing the insulation and increases with increasing the insulation. This is due to the fact that with reduction of the insulation, the thermal capacity of the elements is proportionally decreased and in case of less insulation the cooling of the building grows faster during the nights. And vice versa the greater insulation prevents nighttime cooling of the building, which contributes to higher overheating. The emission of CO_2 is proportional to the increase of energy consumption for heating / cooling.

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Evaluating determinants of energy use in higher education buildings using artificial neural networks – an enhanced study

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ABSTRACT: In the context of meeting a targeted 38% reduction of carbon emissions in the English higher education sector by 2020 against a 2005 baseline an enhanced study has been carried out on the use of artificial neural networks (ANNs) to analyse determinants of energy use in university buildings. Following an earlier pilot study the enhanced study used electricity and heating fuel use data and building parameters for a sample comprising 519 university buildings in southern England. Mean minimum CV-RMSE generalisation errors of between 26% and 39% were found, varying by building activity and energy use type. The trained ANNs were used to simulate five different interventions to reduce energy use in existing buildings from which the changes in energy use were estimated. Findings seemed generally consistent with supporting statistical analysis on the sample and wider building energy theory. Options to improve the robustness of the ANN model are discussed.

1 INTRODUCTION

Carbon emissions associated with the UK higher education sector make up approximately 0.4% of total UK emissions (DECC 2011, HESA 2011). There are a number of significant drivers for UK higher education institutions to manage and reduce their carbon emissions, including utility cost savings, compliance with EU and UK energy-based legislation and schemes and reputational incentives (Altan 2010). In response to these and capital funding initiatives individual institutions in England have developed Carbon Management Plans and have set carbon reduction targets that on average aim to reduce carbon emissions by 38% across the sector by 2020 against a 2005 baseline. This is approximately in line with the UK's overall 2020 carbon reduction target set out in the UK Climate Change Act 2008 (HEFCE 2010, HEFCE 2012). The Carbon Management Plans typically set out guidelines for the construction of new buildings and also interventions to reduce emissions in existing buildings. The majority of UK higher education sector buildings were built during or before the 1970s so potentially there is large scope to improve emissions performance in the existing stock (AUDE 2008).

In order to design and implement carbon emissions reductions in existing university buildings there is a need to understand the scale of reductions that interventions could bring. An approach for this is to use a building energy model such as pseudo-dynamic or dynamic energy simulation software. Whilst this approach can allow interventions to be explored in detail there is evidence of estimated savings not being realized in practice (Sanders & Phillipson 2008) and it can be costly to implement particularly for a number of buildings in a large university estate.

Another approach is to relate building carbon emissions to data for the existing building stock, such as in benchmarking. The current CIBSE TM46 benchmarking system (CIBSE 2008), used as the basis of the England and Wales Display Energy Certificate (DEC) scheme (DCLG 2008), provides general "University campus" electricity and heating fuel benchmarks although university activity specific benchmarks are not included. HEEPI (2006) have developed electricity and heating fuel use benchmarks for nine different university activities. These benchmarks help to compare the performance and indicate scope for improvement but they do not necessarily allow assessment of interventions to reduce carbon emissions.

A previously reported study carried out by the authors (Hawkins et al. 2012) using a sample of 97 buildings in the estates of four London universities found some success in the use of artificial neural networks (ANNs) for analyzing and establishing relationships between building energy use and a number of high-level building parameters. ANNs adopt principles similar to some of those found in biological neural networks and can be used to 'learn' patterns that exist between inputs and outputs in a training dataset. They are seen as a complementary approach to statistical methods and they can work better with pathological datasets (Sarle 2002). A possible application of a well-trained ANN would be a tool to carry out robust and time-efficient energy assessment of early stage new-build and refurbishment design schemes.

This paper describes an enhanced study carried out using a larger sample comprising 519 university buildings in southern England. With the larger sample separate ANNs were trained for four university-specific building activity types. The trained ANNs were then used to estimate building energy savings for five types of refurbishment intervention: conversion to a naturally-ventilated building; upgrading building fabric and systems performance (using age as a proxy); upgrading to double-glazing; changing occupancy characteristics and changing façade glazing ratio. The following sections give an overview of the research method, a summary statistical analysis of the dataset and findings on the ANN training and intervention analysis.

2 METHOD

2.1 *Data collection*

2.1.1 *University building dataset cleaning and quality assurance*

The university building dataset comprised reported actual electricity and heating fuel use (in total annual kWh/m^2 gross internal floor area) and building data from the DEC scheme together with separately collected parameters for buildings in the estates of 29 universities in southern England. DEC data was provided by the Chartered Institute of Building Services Engineers (CIBSE), obtained originally from the UK government. DECs that were considered to be generic (having an Operational Rating of 200 (Bruhns et al. 2011)) or with zero actual energy use values were excluded altogether from the initial dataset. To further improve the quality of the dataset for the analysis buildings were excluded from the electricity and heating use datasets respectively where the corresponding DEC energy values were found to be the following:

- Campus-style: where the energy use in kWh/m^2 matches that of an adjacent building.
- Inconsistent: where the value deviates from that for a previous DEC by greater than 60%.
- An outlier: where the value is greater than 3 standard deviations from the dataset mean.

A quality assurance process was employed with data collected primarily by two researchers and a sample then separately verified by a third researcher. Following data cleaning the electricity and heating fuel use datasets comprised 425 and 416 buildings respectively.

2.1.2 *Building activity*

As discussed previously (Bruhns et al. 2011, Hawkins et al. 2012), university-specific activities are not clearly designated in the DEC scheme so activity types were assigned by observation using university website information. The activity types were selected to allow the range of types found in university estates to be well represented whilst also ensuring a reasonable number (taken as at least 10) featured in each type. Eight activity types were used, as follows: academic LW (laboratory or workshop-based such as science, engineering and medical research); academic non-LW (non-laboratory or workshop-based); administration; residential; library or museum; student union; theatre or conference center; sports center.

2.1.3 *Building parameters*

Associated building parameters deemed to be influential on building energy use were collected to use as training inputs to the ANN. Table 1 describes the parameters and the measured ranges; the data sources and the basis for their inclusion were the same as those used in the previous study (Hawkins et al. 2012) unless otherwise indicated.

Table 1. Building parameters and measured ranges used as inputs to the ANN.

Inputs category	Input factors	Measured data range	ANN input
Primary services type		Natural ventilation, mixed-mode, mechanical ventilation, air-conditioning	Binary: natural ventilation/not
Construction year		1440 to 2012	Continuous
Occupied hours*		1820 to 8568 total annual hours	Continuous
Glazing	Glazing type	Single or double/secondary glazed	Binary
	Glazing ratio	0% to 90% total façade area as glazing	Continuous
Building geometry	Floor area	382 to 46,903m^2	Continuous
	Height	3 to 95m	Continuous
	Fraction exposed	2% to 100% perimeter exposed	Continuous
	Aspect ratio	2% to 100% (depth:length)	Continuous
Adjacent building shading and sheltering	Separate south, west, east, north and southwest factors	0 to 90° elevation angle from half-height of building to top of next building in the respective direction	Continuous
Orientation		90°N (E-facing) to 270°N (W-facing)	Continuous
Weather data** (at nearest base station)	Annual heating degree days**	1587 to 2555 heating degree days at base 15.5°C	Continuous
	Annual cooling degree days**	86 to 414 cooling degree days at base 15.5°C	Continuous
	Annual sun hours	1344 to 2093 total hours	Continuous

*Taken from the DEC reported values provided by CIBSE
**Heating and cooling degree days were taken from data provided by the University of Oxford Environmental Change Institute (UOECI 2013).

2.2 *ANN method*

2.2.1 *Overview*

The ANN analysis was conducted using MATLAB software (version R2012b). Separate analyses were carried out for each activity type although owing to limited data in the respective sets (fewer than 40 buildings) analyses were not carried out for the library/museum, theatre/conference center, sports center and student union activity types. The underlying method used for training the ANN and testing generalization performance was similar to that for the previous study (Hawkins et al. 2012) although key features of the analysis and variation from the previous method are described in sections 2.2.2 and 2.2.3.

2.2.2 *Network architecture and inputs*

The ANN was a single hidden-layer network with biases in the input and hidden layers. Hidden layer sizes of 20, 30 and 40 were tested. Separate ANNs were developed for electricity and heating fuel use. As described in Table 1, all parameters were presented as either binary or continuous inputs mapped into the range -1 to 1. Outputs were the respective energy use in annual kWh/m^2 unmapped but divided by 1000.

The 18 original inputs were run through an initial autoassociative network with 18:40:10:40:18 configuration (Bishop 1995, Kramer 1991), exploiting any existing correlations in the data to reduce the dimension of the input features to 10 with the aim of improving training in the main ANNs. The main ANNs were also trained using only the two inputs for primary services type and construction year to compare with performance on the full set.

2.2.3 *Network training and generalization performance*

The tanh sigmoid training function was used in the hidden layer and a linear sum function was used in the output layer. For the larger academic LW and academic non-LW sets the training data was split 70:15:15 into training, validation and test sets respectively using the MATLAB default (Beale et al. 2012) although in order to keep a similar number of buildings in each test set the other, smaller datasets were split 60:20:20. The ANN was trained using batch training and the Levenberg-Marquardt back propagation algorithm (Bishop 1995). An early stopping method was employed with training stopped when the error on the validation set stopped reducing for five epochs. To improve the likelihood of finding global minima the ANN was run up to 300 times for each hidden layer size with the weights re-initialized randomly each time.

Performance of the training was assessed in terms of the coefficient of variance of the root-mean-squared error (CV-RMSE in %) on the test set. The mean was taken of the lowest CV-RMSE found for ten different test datasets to allow for variation by test set. For comparison a “benchmark” generalization error was estimated for each test set, calculated as the CV-RMSE achieved when using the mean of the training data targets to approximate the test set outputs. The average benchmark generalization error over ten sets was also taken.

2.2.4 *ANN intervention analysis*

For each activity type the best-performing ANNs for each test run were used to carry out the intervention analysis. Five different building interventions were analyzed as follows:
1. Conversion from air-conditioning or mechanical ventilation to natural ventilation.
2. Fabric and system efficiency upgrade, using construction year (set to 2000) as a proxy.
3. Upgrade from single to double glazing.
4. Building management changes to reduce occupancy hours: 20% and 40% reductions.
5. Façade replacement with glazing ratio change: +10% and -10% absolute changes.

For each intervention the relevant inputs for the appropriate buildings in each activity type were adjusted. The modified input sets were run through the autoassociative network to create a new set of features for the main ANN. To avoid extrapolation, where new feature values fell outside of the range of the existing training set the building was omitted. The new features were then run through each of the ten best-performing ANNs. The average percentage change in output was determined for each building and the median change across all buildings was taken.

3 RESULTS

3.1 *Statistical analysis*

3.1.1 *Energy use by activity*

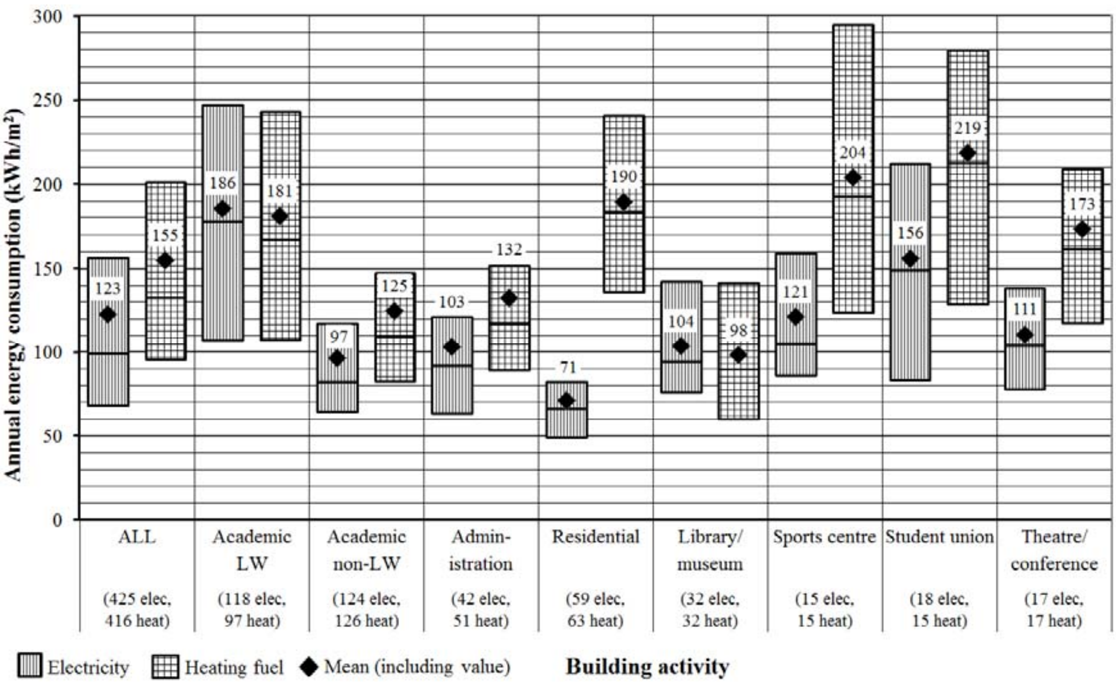

Figure 1. Distribution of energy uses by building activity type.

Figure 1 summarizes the distribution of electricity and weather normalized heating fuel use (using the measured annual heating degree days) by the assigned activity type and indicates a wide variation of energy use by activity. Academic LW shows the highest mean electricity use and high mean heating fuel use, both of which are wide-ranging. Mean electricity and heating fuel uses are low and similar for both academic non-LW and administration. Residential shows the lowest mean electricity use but relatively high and wide-ranging heating fuel use.

3.1.2 *Energy use by primary services type*

Table 2 shows the variation of mean electricity and normalized heating fuel use by primary services type for each activity type. With the exception of theatres/conference centers and residential there is a general trend in each activity of reducing electricity use from the most to least intensive services type. For heating fuel use trends are less clear however for all activities except theatres/conference centers the mean heating fuel use is lowest in either naturally-ventilated or mixed-mode buildings.

Table 2. Mean annual electricity (E) and heating fuel (H) use (kWh/m^2) by services type and activity.

Activity	Air-conditioning		Mechanical ventilation		Mixed-mode		Natural ventilation	
	E	H	E	H	E	H	E	H
Academic LW	244	187	212	179	169	185	141	178
Academic non-LW	161	154	107	141	89	105	89	122
Administration	172	159	116	136	128	157	72	121
Residential	-	-	68	236	58	150	72	187
Library or museum	110	115	122	110	137	76	70	91
Sports center	-	-	132	213	134	271	109	171
Student union	-	-	172	272	164	182	90	116
Theatre or conference	173	109	84	156	121	140	158	258

3.1.3 *Energy use by construction era*

Table 3 shows the variation of electricity and normalized heating fuel use by era of original construction and activity. The eras are aligned approximately with those used by Aude (2008) with changes to include the 1985 and 2000 updates to the Part L energy efficiency standards of the UK Building Regulations. For many activities there appear to be overall trends of increasing electricity use from older to newer eras. For heating fuel use there are downward trends for residential, libraries/museums and sport centers. For the other activity types the highest mean heating fuel use occurs in intermediate eras and use in the older and newer buildings is lower.

Table 3. Mean annual electricity (E) and heating fuel (H) use (kWh/m^2) by construction era and activity.

Activity	Pre-1913		1914-1959		1960-1969		1970-1984		1985-1999		Post-2000	
	E	H	E	H	E	H	E	H	E	H	E	H
Academic LW	156	148	175	174	187	203	181	175	231	172	171	178
Academic non-LW	79	108	86	139	90	153	122	146	92	117	110	85
Administration	62	113	86	147	94	114	120	170	114	113	154	116
Residential	68	217	50	229	62	217	67	172	86	174	81	150
Library or museum	87	114	111	102	94	113	87	99	121	50	147	87
Sports center	-	-	91	307	134	248	58	138	114	219	180	215
Student union	104	97	80	129	207	290	166	196	164	372	85	213
Theatre or conference	35	148	69	216	130	167	74	229	108	160	164	136

3.2 *ANN analysis*

3.2.1 *Network generalization*

Table 4 shows the mean minimum generalization errors found across ten test set runs for the benchmark case, the ANN trained on services type and construction year inputs only and the ANN trained on all inputs. In each case the generalization errors for the ANN trained on all inputs are the lowest indicating a benefit gained by using all available inputs in the dataset. For electricity use the lowest CV-RMSE was found for administration which also showed the greatest change relative to the benchmark. For heating fuel use the lowest CV-RMSE was found for residential which also showed the greatest change. The ranges of mean minimum CV-RMSE are similar for electricity and heating fuel with all values between 26% and 39%.

Table 4. Mean generalization error across 10 test sets for electricity and heating fuel use by activity type.

Activity	Benchmark error	ANN generalization errors			
		2 inputs: services and year		All (18) inputs	
	Mean CV-RMSE	Mean minimum CV-RMSE	Change against benchmark	Mean minimum CV-RMSE	Change against benchmark
Electricity use					
- Academic LW	56%	48%	-15%	39%	-30%
- Academic non-LW	46%	39%	-14%	38%	-17%
- Administration	53%	38%	-28%	26%	-52%
- Residential	43%	37%	-15%	34%	-21%
Heating fuel use					
- Academic LW	45%	40%	-11%	36%	-19%
- Academic non-LW	44%	41%	-7%	36%	-17%
- Administration	45%	35%	-22%	34%	-23%
- Residential	38%	31%	-17%	28%	-26%

3.2.2 *ANN intervention analysis*

Table 5 shows the median energy use change for each intervention as estimated by the trained ANNs. For all activities except for residential the conversion to natural ventilation shows reductions in both energy uses. In almost all cases both fabric upgrade (using construction year change) and the conversion to double glazing indicate increased electricity use and reduced heating fuel use. For occupancy hour reductions some energy use changes are large although trends are less clear. For glazing ratio changes the energy use changes are all small.

Table 5. Median energy use change for each intervention as estimated by the ANN.

Activity	1. Convert to natural ventilation	2. Fabric upgrade (year change)	3.Upgrade to double glazing	4. Reduce occupied hours		5. Change glazing ratio	
				Reduce by 20%	Reduce by 40%	Increase by 10%	Reduce by 10%
Electricity use							
- Academic LW	-24%	+11%	+25%	-0.9%	-2%	-0.06%	+0.06%
- Academic non-LW	-8%	+6%	+19%	+5%	+19%	-0.01%	+0.01%
- Administration	-8%	+1%	+33%	-6%	-13%	+0.1%	-0.1%
- Residential	+6%	+8%	+15%	-11%	-3%	+0.05%	-0.05%
Heating fuel use							
- Academic LW	-11%	-1%	-12%	-2%	-7%	-0.02%	+0.02%
- Academic non-LW	-3%	-2%	-16%	+1%	+7%	+0.01%	-0.02%
- Administration	-11%	-0.1%	-4%	+3%	+7%	+0.03%	-0.02%
- Residential	+7%	-3%	+3%	+1%	-3%	+0.09%	-0.09%

4 DISCUSSION

4.1 *University building energy use determinants*

The study has demonstrated wide variation in both types of energy use by activity, services type and construction era. The statistical analysis indicated that for a range of university-specific activity types naturally-ventilated buildings generally have lower electricity and heating fuel use. This is reflected by the ANN intervention analysis which showed median energy reductions for conversion to natural ventilation for almost all activities. Reductions were not shown for residential buildings although in the sample these were largely all naturally-ventilated so this may be a training restriction.

For all activities the intervention analysis indicated median reductions of up to 3% in heating fuel use for conversion to the equivalent of a post-2000 building which appears to be well-founded given the likely improved fabric thermal performance and system efficiencies relating to Part L of the UK Building Regulations. Conversely electricity use is shown to increase in all cases which is seemingly counter intuitive. The higher electricity use may relate to other factors such as higher ICT densities in newer buildings. Whilst a significant finding this suggests a limitation of using building age alone as a proxy for fabric and system performance.

Changes of the same direction (except for residential heating fuel use) but greater magnitude are shown for conversion to double glazing. In part at least this may owe to the improved thermal performance reducing heating demand and possibly increasing mechanical ventilation and cooling requirements. It is also possible that this factor is still correlated with building age so similar effects to those above may be occurring.

The intervention analysis also showed some significant changes in energy use with reduced occupied hours although the direction of changes varied between energy uses and activity types. This suggests the ANN was sensitive to the occupied hours inputs although the analysis might be improved by better description of the building occupancy characteristics.

The proposed energy use changes associated with glazing ratio modifications are all small indicating that overall this factor is relatively weak in influencing end energy use. However greater variation might still be found if it were broken down into different façade orientations.

4.2 *Use of ANNs for university building energy use determinant analysis*

Relative to the pilot study (Hawkins et al., 2012) use of the larger training dataset has allowed analysis by activity type and has shown some improvements in generalization (% CV-RMSE reduction) for electricity use. For heating fuel use however generalization improvement was not observed. A possible cause for this may be the greater variety of institutions and building types and much wider geographical area with the differences not sufficiently described by the building parameters used. A further enlarged dataset may help to reduce error, particularly given the high diversity of activity types within university estates, however it is proposed that at this point greater improvements might be made by increasing the extent and precision of inputs in order to more closely describe the building energy use characteristics. A large number of potential additional inputs exist although the following key inputs are suggested:

- Breakdown of building areas by space use, for example lecture theatres, offices, laboratories, workshops, catering, special use and balance areas.
- Higher resolution building energy data to isolate significant base loads and separable uses.
- Direct values of the building thermal performance such as fabric U-values and air tightness.
- Efficiency and loads of systems including heating, lighting, cooling and ventilation.

The ANN intervention analysis showed findings that aligned with both the observed statistical variations in the dataset and with general building energy theory. Such a method could provide advantages over other energy assessment approaches such as benchmarking and dynamic simulation as it allows estimations to be tailored to the specific building characteristics without a significant modeling burden. For robustness it would be necessary to improve the generalization error of the underlying ANNs. The addition of inputs as listed above would also extend the scope of interventions that could be assessed. It is recommended that a more developed model is applied in a real context and validated using measured data from refurbishment case studies.

5 CONCLUSION

A study has been carried out using data from 519 university buildings in southern England to train ANN models with a selection of building parameters as inputs and end energy use as the output. It was found that the models were able to estimate energy use for an unseen test set with a mean minimum generalization error of between 26% and 39% depending on building activity and energy use type. It is proposed that generalization may be improved further by the addition of inputs to provide a tighter representation of the building energy use characteristics. Suggested principal inclusions are breakdowns of building spaces, clearer description of the building fabric and systems and higher resolution energy data.

An intervention analysis carried out using the trained ANNs to simulate building modifications proposed some energy use changes that seemed consistent with parallel statistical findings and building theory. Findings may have been limited by the available training data. Such a model could be of high value for early stage assessments of building refurbishment schemes to meet higher education sector carbon emissions reductions targets. Whilst the study has indicated some success, further improvement in the generalization performance of the underlying ANNs would be necessary to provide a stronger model for this type of analysis.

6 ACKNOWLEDGEMENTS

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Energy Efficiency of Photovoltaic Façades for Different Latitudes in Portugal

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ABSTRACT: The climate and energy package is a set of binding legislations that ensures European Union meets its ambitious climate and energy targets for 2020. These targets, known as the "20-20-20" targets, have set three key objectives: a 20% reduction in the EU greenhouse gas emissions, a 20% rise in the share of EU energy consumption produced from renewable resources and a 20% improvement in the energy efficiency. More renewable energies will enable the EU to lower greenhouse emissions and make it less dependent on imported energy. Boosting the industry of renewables will encourage technological innovation and employment in Europe. On this topic, photovoltaic façades are known to be a solution that provides both energy efficiency and environmental performance of buildings. This paper reports on a study of façade systems that have incorporated photovoltaic panels. Computational simulations using Solterm 5 were conducted to analyze the features and parameters that define more efficient systems for the latitudes in Portugal. The results show the high potential of the use of the proposed technology in Portugal, especially in the Southern region, because of its latitude. Regarding energy efficiency and environmental performance, inclined polycrystalline silicon solar panels achieved the best results and the most efficient panel was Kyocera KC167G-2, followed by BP 3160. The comparison between simulation results and results provided in the literature shows that the use of Solterm 5 is viable to the analysis of the energy efficiency of photovoltaic systems in façades.

1 INTRODUCTION

The reduction in the CO_2 emitted into the atmosphere and resulting from energy consumption has been a global concern over the past few years. The European Union has developed a set of documents to regulate the reduction in both energy consumption and emissions of greenhouse gases, increasing the share of renewable energies by 2020 (Directive 2010/31/EU, 2010). These targets, known as the "20-20-20 targets", have set three key objectives: a 20% reduction in the EU greenhouse gas emissions, a 20% rise in the share of EU energy consumption produced from renewable resources and a 20% improvement in the energy efficiency.

The use of photovoltaic façades has been a strategy to achieve gains in renewable energy and environmental performance of buildings. Through the building façade it is possible to harness solar radiation energy, contributing to better energy and environmental performance of buildings. In some cases, photovoltaic panels can replace glazed façades, solar protection devices and other elements of buildings (Sacht, 2013).

The main types of photovoltaic cells for use in façades are monocrystalline silicon cells, polycrystalline silicon cells and amorphous silicon cells, also known as thin-films. Monocrystalline silicon cells are the most used in solar cells (Figure 1). Polycrystalline silicon cells consist of a large number of small crystals as thick as a human hair and their manufacturing process is cheaper than that of crystalline silicon (Figure 2) (Altener, 2004).

Amorphous silicon cells (thin films) are made on a support of glass or other synthetic material, onto which a thin layer of silicon is deposited. The efficiency of this type of cell is lower than that of the crystalline cell, but the current produced is reasonable (Figure 3).

Among the thin films is also the CdTe cell. CdTe material has been used for applications to calculators and solar modules. These modules, usually in the form of glass panels in a brown / dark blue tone, display a good aesthetic aspect. The production cost of a CdTe cell is low on a large-scale. The CdTe technology has emerged as a major competitor in the market for photovoltaic energy production. Its high efficiency of conversion of solar energy into electric energy is one of its main advantages (Figure 4).

Another competitor in the photovoltaic market, also in integrated applications to buildings is the solar cells fabricated from the family of compounds based on copper indium diselenide ($CulnSe_2$ or simply CIS) and diselenide, copper indium gallium (Cu (InGa) Se_2, or simply CIGS), mainly because of their potential to achieve relatively high efficiencies.

Among the commercially available thin films, CIGS modules have shown the best photovoltaic performance, therefore many companies have been investing in this technology (Rutter, 2004). Differently from traditional silicon cells, CIGS cells can be printed on a material roll, facilitating their transport and installation. Their civil construction uses are limitless and they can be applied to façades, roofs, awnings, etc. (Figure 5).

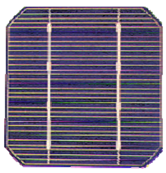
Figure 1. Monocrystalline silicon cell.

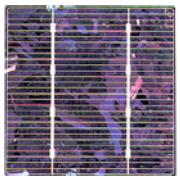
Figure 2. Polycrystalline silicon cell.


Figure 3. Thin-Film.

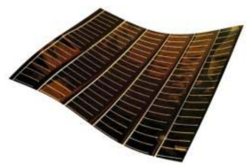
Figure 4. CdTe Cell.


Figure 5. CIGS Cell.

Table 1 shows the efficiency of each technology presented and other types of recent cells.

Table 1. Maximum Efficiency of Photovoltaic Technologies. (Green et al. 2012.)

Material	Cells	Eficiency %
Silicon	Si (crystalline)	25,0%
	Si (multicrystalline)	20,4%
	Si (thin film transfer)	19,1%
III-V Cells	GaAs (thin film)	28,3%
	GaAs (multicrystalline)	18,4%
	InP (crystalline)	22,1%
Thin film Chalcogenide	CIGS (cell)	19,6%
	CdTe (cell)	16,7%
Amorphous/Nanocrystalline Si	Si (amorphous)	10,1%
	Si (nanocrystalline)	10,1%
Photochemical	Dye sensitised	11,0%
Organic	Organic thin film	10,0%
Multijunction Devices	GaInP/GaInAs/Ge	34,1%
	a-Si/nc-Si/nc-Si (thin film)	12,4%
	a-Si/nc-Si (thin film cell)	12,3%

GaAs-based multijunction devices are the most efficient solar cells. Presently, a new generation of multi-junction solar cells with efficiency potential as high as 50% under "concentrated sunlight" has been developed (Peach, 2013). A large number of computational tools have been used for studies on the photovoltaic panels. Gonçalves (2011) compared the results of computer simulations conducted in Portuguese software Solterm 5.0 and case studies for two buildings in Lisbon (Solar XXI and Natura Towers). The values for the energy production were close to those found in systems installed in existent buildings (Table 2). Differences between simulation results and a real situation are expected, however the results from simulation tools approximate those found in real cases.

Table 2. Results provided by Gonçalves (2011).

Characteristics	Natura Towers	Solar XXI	Solterm 5.0 Software	
Area (m^2)	217,4	96,0	100,8	100,8
Cells	Polycrystalline	Polycrystalline	Polycrystallin e	Polycrystallin e
Manufacturer	-	BP 3160 S	BP 3160	BP 3160
Type of System	Autonomous	Connected to Electrical Grid	Autonomous	Connected to Electrical Grid
Energy Production (kwh/ano)	21925	12108	11776	11740
Energy Production (kwh/ano.m^2)	101	126	117	116

The use of photovoltaic panels in inclined planes maximizes the solar radiation absorption. The ideal for the panel position is an inclination approximately equal to the latitude of the location. In the northern hemisphere, photovoltaic panels should face the southern solar orientation (Castro, 2011).

This paper presents part of a study that includes a photovoltaic mobile module (Sacht et. al., 2010; Sacht, 2013). It proposes photovoltaic panels for different latitudes of Portugal and analyzes the characteristics of the most efficient panels regarding energy production.

2 METHODOLOGY

This study includes the development of parameters for a photovoltaic system for façades in Portugal. Computational simulations were carried out applying Solterm 5.0 software to analyse the energy generation and compare the results.

2.1 *Criteria for the Photovoltaic System*

Table 3. PV Panels simulated in Solterm 5.0.

PV Panels	BP 3160 	M75S 	KC167G-2 
Manufacturer	BP Solar	Siemens	Kyocera
Technology	Polycrystalline Silicon	Monocrystalline Silicon	Polycrystalline Silicon
Rated Power $_{max}$ (W)	160	74.8	167
Voltage (V)	24.0	12.0	12.0
Open Circuit Voltage (V)	44.2	22.0	28.9
Current (A)	4.55	4.40	7.20
Short Circuit Current (A)	4.80	4.80	8.00
Eficiency (%)	12.7	-	16.0

In the simulations of the PV modules three Portuguese cities (Bragança, Coimbra and Évora) and southern solar orientation, ideal for this type of system in localities of the northern hemisphere were considered. The PV panel was simulated in both vertical and inclined positions. The criterion for the selection of the cities was their geographical location, especially latitude, which is directly related to the solar radiation and solar irradiation. The inclination of the panels is different according to the city. The software allows optimizing the inclination, which is usually close to 30 º for Portugal.

The database of SolTerm 5.0 contains only three types of photovoltaic modules, certified for use in Portugal, therefore only PV panels from this database were used in the computer simulations (Table 3).

2.2 *Simulations of Photovoltaic Modules for the Façade System*

The analysis of the photovoltaic cells for use in the façade system was based on the database of SolTerm 5.0 software, which is used in Portugal by legislation to quantify solar energy. It is a guideline of the *"Regulamento das Características de Comportamento Térmico dos Edifícios"* (RCCTE, 2006) code.

2.3 *Solterm 5.0*

Solterm software simulates the performance of solar thermal and photovoltaic systems for climates of Portugal in several locations. It calculates the thermal contribution of the system to the house energy performance, which is then integrated in the energy certification calculations. It also optimizes the solar energy production according to the optimal orientation and inclination. It contains updated information on types of systems, panels, brands and average investment, allowing the assessment of the systems' economic revenue. The software is not free and has been developed by *"Laboratório Nacional de Energia e Geologia"* (LNEG) (National Laboratory of Energy and Geology) and adjusted especially to the climatic conditions and techniques of Portugal.

The simulations required information about the configuration/system design, operation and control strategies, horizontal solar radiation and hourly environment temperature, obstructions and shadings, and technical characteristics of the system components and consumption (INETI, 2007) (Figure 6).

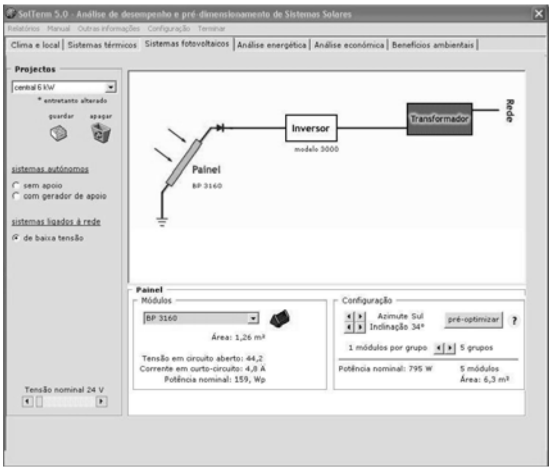

Figure 6. Solterm 5.0 software main screen.

3 RESULTS

This section provides the results of computer simulations for the PV modules in terms of energy production. For a better understanding of the graphs two acronyms have been added next to the panel name: "VE" panel positioned vertically at a 90º angle and "IN" panel inclined at angles near 30º, according to the optimization of positioning by location obtained by means of Solterm 5.0.

3.1 *Energy Production Results*

Results show that for all locations analyzed, the highest energy production was observed with the use of Kyocera polycrystalline panels KC167G-2 and BP 3160, whose values were similar (Figure 7). For Bragança, with the use of inclined modules, the increments in terms of energy production were 57.24% for BP 3160, 52.27% for Kyocera KC167G-2 and 61% for Siemens M75S, confirming that the inclined positioning provides more efficient energy capture. The lowest energy efficiency was observed for the Siemens M75S panel positioned vertically, whose energy production was 4.6 times lower than the best one (Kyocera photovoltaic panel KC167G 2-inclined).

For Coimbra the increases in terms of energy gains with the inclination of the panels were 60.14% for BP 3160, 56.07% for Kyocera KC167G-2 and 63.52% for Siemens M75S panel. Again, the lowest efficiency was observed for the Siemens M75S panel positioned vertically. For Évora, the increments in terms of energy gains with the inclination of the panels were 63.26% for BP 3160, 56.22% for Kyocera KC167G-2 and 68.46% for Siemens M75S.

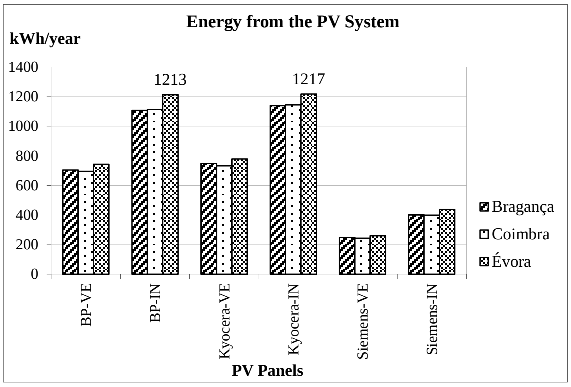

Figure 7. Energy from the PV System (kWh/year).

3.2 *Avoidance of both Primary Energy Consumption from Fossil Fuels and Emission of Greenhouse Gases*

Results of avoidance of primary energy consumption from fossil fuels were also provided by Solterm 5.0. Higher-efficiency panels showed greater savings in the primary energy consumption from fossil fuels (Figure 8).

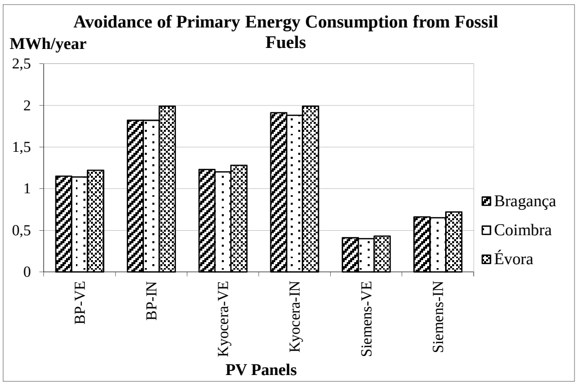

Figure 8. Avoidance of Primary energy consumption from fossil fuels.

The avoidance of emissions of greenhouse gases was higher for the use of systems with an optimized inclination (Figure 9).

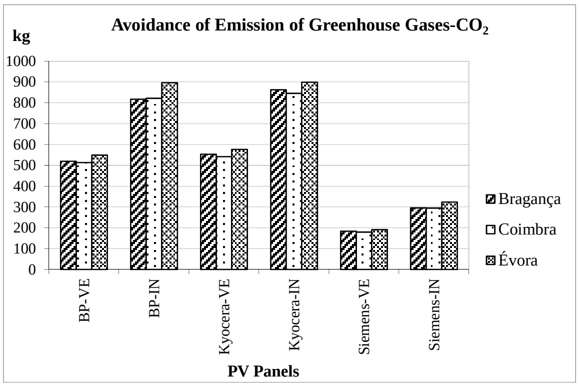

Figure 9. Avoidance of Emission of greenhouse gases.

The results show the best performance in terms of energy generation of Kyocera KC167G-2_ and BP Solar 3160 panels. The photovoltaic Kyocera KC167G-2 panel was the most efficient. Table 1 shows the order of efficiency in the energy production.

Table 3. Order of Efficiency in the Energy Production of Photovoltaic Systems

Order of Efficiency of Photovoltaic Systems
1st Kyocera KC167G-2 – IN
2nd BP Solar 3160 - IN
3rd Kyocera KC167G-2 - VE
4th BP Solar 3160 - VE
5th Siemens M75S – IN
6th Siemens M75S – VE

4 CONCLUSIONS

The use of the photovoltaic Kyocera KC167G-2 panel (polycrystalline silicon) showed the best performance among all, but the performance of BP Solar BP 3160 panel (polycrystalline silicon) was very similar. A general analysis showed an increase in terms of energy gains for the simulations that considered the inclined panels. The primary energy consumption from fossil fuels and the emission of greenhouse gases were reduced with the use of inclined PV panels.

The use of monocrystalline or polycrystalline photovoltaic cells in the systems indicates the most efficient energy generation by SolTerm software, for application in Portugal. The PV modules must be installed in the southern solar orientation (for the Northern hemisphere) and in the northern solar orientation (for the southern hemisphere), as in Brazil, and could be movable to increase the capture of energy.

The photovoltaic panels currently used in façades are positioned vertically. However, the possibility of inclining them as a "Sunflower" may offer higher efficiency in terms of solar radiation capture and increase of energy generation (Sacht, 2013). The mobility of photovoltaic modules for the façades would allow the search for the southern, eastern and western solar orientations (in Portugal) and northern, eastern and western orientations in an adaptation to the system in Brazil. The SolTerm 5.0 database contains only the three types of photovoltaic modules certified for use in Portugal, however many other more efficient modules can be found in the market.

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Bioclimatic Buildings Strategies for the Climate of Araras City, São Paulo - Brazil

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ABSTRACT: The concept of bioclimatic architecture or passive solar architecture can be defined as an architecture that includes the climate as an important variable in the design process. Through the use of bioclimatic strategies the environment comfort can be obtained naturally for users of buildings, which depending on the climate, the construction techniques and the type of use. Considering these aspects, the main objective of this work is to identify bioclimatic strategies for buildings for the climate of Araras city, countryside of São Paulo State - Brazil, based on climatic characterization of the city and in the study of design guidelines indicated by the Brazilian Code NBR 15220-3, the Brazilian Bioclimatic Zoning. According to the code, the climate of Araras is inserted in Bioclimatic Zone 4. For this climate the main indicated strategies for winter are the use of solar passive heating and massive internal walls in buildings. For summer, the use of evaporative cooling and ventilation are indicated. Based on this information were established initial guidelines for thermal comfort and energy efficiency for projects of buildings in the climate of Araras-SP.

1 INTRODUCTION

The architecture has sought throughout history to develop means of environmental control that can provide shelter and comfort for the man, and the mood climate of each city has been the determining factor in defining the architectural concepts, materials and construction techniques used. The study of climate and its relation to design practice is increasingly becoming a differential of the good architecture.

There are different terms related to architecture as "Green Architecture", "Ecological Architecture", "Bioconstruction", "Bioclimatic Architecture", "Eco-Efficient Architecture", "Passive Solar Architecture." There are also different ways of relating architecture with the environment with similar or close meanings, and they are directly related to the sustainable architecture.

The bioclimatic project covers the needs of the human being in thermal, lighting and acoustic aspects, with a concern about the weather conditions and the use of techniques including the study of sunlight, heating and air movement through the building envelope when necessary. This for specific hours of the day and months of the year, using available materials in the region and, in addition, trying to integrate the building with the surrounding space (Givoni, 1998 apud Sacht, 2013). It is believed that the incorporation of bioclimatic building concepts is one of the cheapest and most efficient practice for energy saving.

There are two major factors in the context of bioclimatic architecture, they are: a multidisciplinary approach required to develop an efficient project, and its insertion into the sustainability subject to the search for an efficient passive design is necessary to understand that there is not a perfect solution and that can be applicable to all situations, but numerous mechanisms that must be selected in order to find an appropriate solution for a given site

(Lanham et al, 2004), this will give birth to a more sustainable architecture.

Considering these aspects, the bioclimatic architecture subject is extremely important to the current context of architecture, both in relation to buildings and the urban environment. This justifies the importance of the development in the area. In this research, appropriate bioclimatic strategies to the climate of Araras have been established. The climate characterization of the climatic data is indispensable instruments of assessment and construction planning of sustainable buildings.

2 OBJECTIVES

The main objective is to identify bioclimatic strategies for buildings for the climate of Araras city, countryside of São Paulo State - Brazil, based on climatic characterization of the city and in the study of design guidelines indicated by the Brazilian Code NBR 15220-3, the Brazilian Bioclimatic Zoning: Thermal performance of buildings" (ABNT , 2005). This paper presents the initial results of a research in progress.

3 METODOLOGY

For the development of this work it were respected the following rules: climatic characterization of Araras city; application of NBR 15220-3 (survey of indicated bioclimatic strategies and compared with the strategies set by the ZBBR program); detailing strategies and observation using them in buildings located in the city of Araras.

3.1 *Climate Characterization of Araras*

The climatic characterization of Araras was based on climatic classification of Köppen-Geiger, best known for Köppen climate classification, which is the classification system of global climatic types, most commonly used in geography, climatology and ecology. This classification was proposed in 1900 by climatologist Wladimir Köppen, and it have been improved by him in 1918, 1927 and 1936 with the publication of new versions, prepared in collaboration with Rudolf Geiger (origin of the name Köppen-Geiger) (Sá Jr., 2009). It were also consulted the climatological data of Araras provided by the Center of Agrarian Sciences of the Department of Natural Resources and Environmental Protection of the Federal University of São Carlos (UFSCar).

3.2 *Application of Brazilian Code NBR 15220-3*

According to "NBR 15220-3: Thermal performance of buildings", Brazil is divided into eight different bioclimatic regions (Figure 1). The eight areas are relatively homogenous regarding to the weather. For each of them there is a set of technical and constructive recommendations, in order to optimize the thermal performance of buildings through a better climatic adaptation (ABNT, 2005). Araras is included in Bioclimatic Zone 4 (Figure 2).

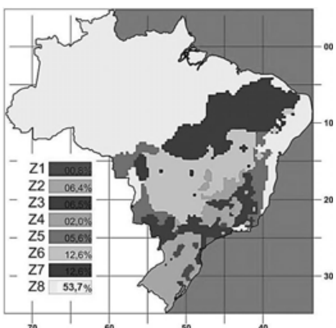


Figure 1. Brazilian Bioclimatic Zoning. (Adapted from Yuriko 2012).

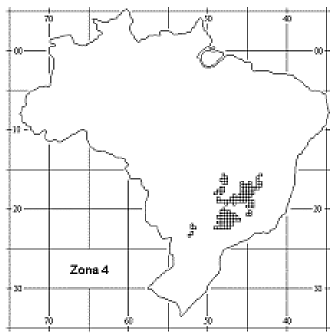


Figure 2. Localization of Bioclimatic Zone 4 on Brazilian map. NBR 15220-3 (ABNT, 2005).

Bioclimatic Zone is a graphic result of the intersection of three different data: human thermal comfort zones, weather data of a region and design strategies (Yuriko, 2012).

Roriz (2012) elaborated a new proposal for the Brazilian Bioclimatic Zoning (Figure 4). According to him, there are several methods of climatic classification, aimed at different goals, such as agriculture, biology, geology, etc. His new proposal applies two parameters to classify climates, the both are indicators of the climatic strictness of each point in the territory: the first is proportional to the total annual heating degree-hours; the second, proportional to the total annual cooling degree-hours. To set these parameters, the author has adopted the comfortable temperature gaps of the Bioclimatic chart proposed by Givoni (1992) for countries in development, in other words, 18 to 28ºC, 18ºC, the lower limit of the Comfort Zone and 28ºC, an average between upper limits for different levels of moisture. Were then calculated values of GhC and GhF for each point on the climatic map and based on the analysis of the results, were defined 16 Bioclimatic Zones.

The Table 1 shows the thermal conditioning strategies that are indicated by the NBR 15220-3 (ABNT, 2005), for Bioclimatic Zone 4 (BCDFI) according to Bioclimatic Chart (Figure 3).

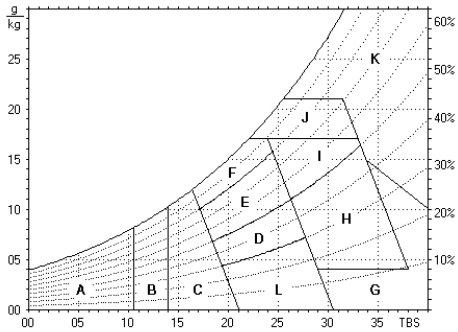


Figure 3. Bioclimatic Charter adapted. Reference: NBR 15220-3 (ABNT, 2005)

Figure 4. Second proposal for the Brazilian Bioclimatic Zoning. Reference: Roriz (2012).

Table 1. Detailing strategies for thermal conditioning

Strategies	Characterization	Detailing Strategies
B	Heating solar zone for edification	The shape, orientation and arrangement of the building, to the correct orientation of glazed surfaces, may contribute to optimize its heating during cold periods through the incidence of solar radiation. The color of the external components also has an important role in the heating of environments through the use of solar radiation.
C	Thermal mass zone for heating	The adoption of massive internal walls can help to keep the interior of the building warmed.
D	Thermal comfort zone (low humidity)	Characterizes the thermal comfort zone (the low humidity).
F	Dehumidification Zone (air renewal)	The thermal sensations are improved through dehumidification of environments. This strategy can be obtained through the renewal of indoor air by outdoor air through the ventilation of environments.
H e I	Thermal mass Zone for cooling	More pleasant indoor temperatures can also be obtained through the use of walls (external and internal) and coatings with higher thermal mass, so that the stored heat in its interior during the day returns to the external during the night, when the outside temperature decreases.
I e J	Ventilation Zone	The cross ventilation is obtained through the circulation of air through the edification environments. It means that if there are windows only on a façade of the environment, the door should be left opened for cross ventilation. It should also be alert to the predominant winds of the region and of the surroundings because the surroundings can significantly alter the direction of the winds.

Reference: Based on NBR 15220-3 (ABNT, 2005).

The ZBBR program was used to confirm the constructive guidelines indicated by NBR 15220-3 (ABNT, 2005), because in the code version, Araras city is not included in the detailed list of municipalities and bioclimatic strategies, being that on the program the strategies are indicated based on interpolated climatic data. The ZBBR program, developed by Roriz (2004) presents the bioclimatic classification of Brazilian municipalities and constructive guidelines are established for social interest housing, also based on NBR 15220-3.

3.3 *Detailing of the Passives Strategies and Observation of Use in Buildings of Araras*

Through a qualitative survey was analyzed the use of the passive strategies in the city of Araras, based on the characteristics of the autochthonous architecture of the city.

4 RESULTS

4.1 *Characterization of climate of Araras*

The climate of Araras presents an annual average temperature of 21.4°C, with the minimum in July of 17.7°C and maximum in February of 24,1°C. The annual precipitation in 2011 was 1649.80 mm with hydric deficit between the months of July and August (UFSCAR, 2003). The air temperature regime follows closely the seasons, varying gradually, with elevated monthly averages in summer, slight decrease in the fall, lower values in winter and growth in spring. This climatic pattern is typical of the Cwa climate for the Köppen classification (Table 2) (mesothermal with hot summers and dry season of winter, with average temperature below 18 C, but superior than 3°C in the coldest month, and average temperature over 22°C in the hottest month) (Valladares et.al., 2008).

Table 2. Fundamental Regions and Climatic Classes of Araras-SP, by the Classification of Köeppen.

Climatic Groups	Fundamental Regions	Climatic Classes
C Rainy Temperate Climate And Moderately Hot.	Cw Mostly Temperate Climate With Summer Rains And Dry Winter.	Cwa Mostly Temperate Climate With Dry Winter And Hot Summer.

Reference: Sá Jr. (2009).

4.2 *Application of the Code NBR 15220-3 for the climate of Araras*

Strategies for a project can differ according to the climate of each region where they are applied, but in general, using the shape of the building, the layout of the openings and the thermal performance of the materials. There were initially compiled the established guidelines by the code for Bioclimatic Zone 4, in which the city of Araras is included. Regarding the ventilation vents, the NBR 15220-3 indicates the strategies presented in Table 3.

Table 4 summarizes the bioclimatic strategies for the Bioclimatic Zone 4 for the winter and the summer. In relation to the external walls and the roof, the code indicates of the properties of materials according to Table 5.

Table 3. Bioclimatic Strategies for Vents/Shading for the Bioclimatic Zone 4.

Zone	Vents for Ventilation A (% of the Floor Area)	Shading
4	Averages $15\% < A < 25\%$	Shade the vents.

Reference: Based on NBR 15220-3 (ABNT, 2005).

Table 4. Bioclimatic Strategies According to the Bioclimatic Zone 4.

Bioclimatic Zones	Bioclimatic Strategies	
	Winter Heating Season	Summer Cooling Season
4	A) Solar heating of the building B) Heavy internal walls (thermal inertia)	A) Evaporative cooling and massive wall for cooling B) Selective ventilation (in hot periods where the indoor temperature are higher than the outdoor)

Reference: Based on NBR 15220-3 (ABNT, 2005).

Table 5. Bioclimatic strategies for internal walls and roofs for the bioclimatic Zone 4.

Zone 4	*U*	*Φ*	*Fso*
Internal walls	≤ 2.20 (massive)	≥ 6.50	≤ 3.50
Roof	≤ 2.00 (isolated lightweight)	≤ 3.30	≤ 6.50

Reference: Based on NBR 15220-3 (ABNT, 2005).

Where U = thermal transmittance of a component (W/m².K); φ = heating time delay of a component (in hours); and *FSo* = solar factor of opaque elements (%).

The verification of the strategies mentioned on the Table 4 was made through the ZBBR program, thus obtaining constructive guidelines for Araras-SP, as in the Figure 5.

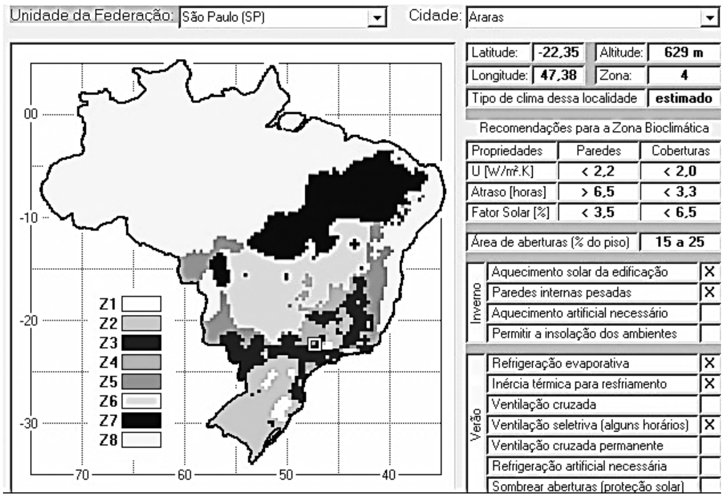


Figure 5. Brazilian Bioclimatic Zoning and Constructive Guidelines for the climate of Araras City.
Reference: ZBBR Program (Roriz, 2004).

4.3 *Detailing the Strategies for Winter*

Solar heating of the building

Large glazed openings allow the entrance of solar radiation, warming the environment. In Figures 6 to 8 below are observed images of buildings located in Araras, which are application examples of such strategies, through the use of glazed (direct radiation system gain).

It is important to use the adequate glass according to the climate. One can quote the case of the glazings in the green and blue colors, for example, which allow reasonable transmission of radiation in the visible region, therefore providing a good daylighting, while attenuates infrared radiation, thereby reducing the heat that occurs due to the radiation from that region. It is known that these color glasses have a tendency to decrease the transmission of radiation in higher wavelengths (Caram, 1998; Caram, 2002).

Figure 6. Glazed façade

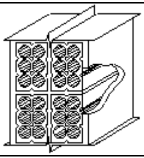
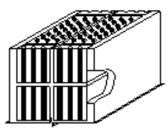
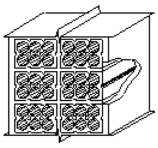
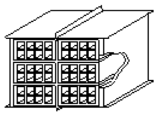
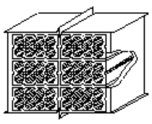
Figure 7. Façade with large glazed windows, and protected balcony.

Massive Internal walls

Corbella and Corbe (2011) describes that "the inner walls intervene on the persons´s comfort, with other internal elements of construction, playing a role in thermal inertia." it is also said that the effusivity of materials, which have areas exposed to indoor air (and exchanging heat with it), can produce a dampening of the outdoor temperature variations." According to the normalization, they are advised for Araras, the types of internal walls in accordance with Table 6.

It should be noted that the use of thicker walls is visible in historic buildings of the city, whose vertical windbreak are solid brick. For choosing these solutions for internal walls must be considered the solutions that are more consistent with the reality of building systems for vertical sealing that are used in local construction as well as the final cost of the solution.

Table 6. Thermal transmittance, thermal capacity and thermal delay for walls que may be used in constructions in Araras-SP.

WALL	DESCRIPTION	*U*	*CT*	*φ*
	Double masonry wall Horizontally perforated bricks Brick dimensions: 10,0 x 15,0 x 20,0cm Thickness of the mortar: 1,0cm Thickness of mortar plastering: 2,5cm Total Thickness: 26,0cm	1.52	248	6.5
	Double masonry wall Vertically perforated bricks Brick dimensions: 12,0 x 11,0 x 25,0cm Thickness of the mortar: 1,0cm Thickness of mortar plastering: 2,5cm Total Thickness: 30,0cm	1.54	368	8.1
	Double masonry wall Horizontally perforated bricks Brick dimensions 10,0 x 15,0 x 20,0cm Thickness of the mortar: 1,0cm Thickness of mortar plastering: 2,5cm Total Thickness: 36,0cm	1.21	312	8.6
	Double masonry wall Horizontally perforated bricks Brick dimensions: 9,0 x 19,0 x 19,0cm Thickness of the mortar: 1,0cm Thickness of mortar plastering: 2,5cm Total Thickness: 44,0cm	1.12	364	9.9
	Double masonry wall Horizontally perforated bricks Brick dimensions: 10,0 x 20,0 x 20,0cm Thickness of the mortar: 1,0cm Thickness of mortar plastering: 2,5cm Total Thickness: 46,0cm	0.98	368	10.8

Reference: Based on NBR 15220-3 (ABNT, 2005).

Where *U* = thermal transmittance of a component (W/m².K); *CT* = thermal capacity of a component [kJ/(m².K)]; and *φ* = heating time delay of a component (in hours).

4.4 *Detailing the Strategies for Summer*

Evaporative Cooling

Evaporative cooling is a strategy used to increase the relative humidity and decrease its temperature, and can be obtained directly or indirectly (Lamberts et al., 2000). Like examples can be cited the use of vegetation, water sources (Figures 8 e 9) or other features that result in the evaporation of water, providing an increase of relative humidity. However, an indirect form can be obtained through water tank systems that pour the water on the coatings.

Figure 8. Araras`s square with a body of water.

Figure 9. Fountain located in Araras´s square.

Selective Ventilation

Ventilation is a natural cooling strategy of the constructed environment, replacing the internal air (warmer) by the external (cooler). The architectural solutions most commonly used are cross ventilation, ventilation of the cover, and ventilation of the floor under the edification (Lamberts et al. 2000). For buildings in Araras is necessary that ventilation be selective, i.e. be used and / or be available only at certain hours of the day, for example in warmer periods. Figure 10 shows an example of cross ventilation which occurs due to the existence of openings in adjacent walls, forming zones with different air pressures. On the face of incidence of the wind there is a high pressure zone, and on the opposite side there is a low pressure zone, thus generating the movement of air. In the case of environments without opening for output wind, it is used the unilateral ventilation.

Figure 10. Windows of a building in Araras, which provide cross ventilation.

5 FINAL REMARKS

Currently the relationship between architecture and the climate in the preservation of the environment and energy saving have had greater importance. In this context, the bioclimatic architecture joins the search for answers in the appropriate integration of man and his environment, through changes in design process and execution of habitable spaces, reverberating throughout the productive chain of the construction industry.

Therefore, this initial phase of this research brings up as a contribution the collecting of bioclimatic strategies for the municipality of Araras, through the study of NBR 15220-3 (ABNT, 2005), and as initial results it could be verified that the application of such strategies aim at a better environmental comfort for the users, with consequent energy saving.

This information will form the basis for architects and engineers that work on development of projects in Araras, that most of the time are unaware about the possible application of such strategies, well as for architecture students that may have initial references to develop projects adequate to the climate conditions. The use of such strategies, joint with the correct selection of materials, contributes to the rise of environmental comfort, as well as saving resources and energy efficiency.

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Protocol of control for the model for calculating the energy efficiency of existing buildings

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ABSTRACT: The European energy EPBD (Energy Performance of Buildings Directive) regulations and its adequacy to the norms draw a design guideline based on the benefits that improve the task of designing new buildings and checking existing buildings, not only from the aesthetic or practical considerations, or even the point of view of urban planning or accessibility, but also taking into account the optimization of energy consumption in buildings.
The pending issue is how to certificate existing buildings with a practical sense through a process with the following characteristics: easy, economic and reliable.
What information is needed from existing buildings for this certification protocol?
This document will try to clarify and brighten up the EPBD through a good control of the model of an existing building efficiency certification, which means that “with a good control protocol of the model” we will have “a good energy efficiency certification for existing buildings” as a consequence.

1 INTRODUCTION - EPBD CONTROL

As a background information, according to the new Directive 2010/31/EU (EU, 2010), the certification procedure for energy efficiency means that an "independent expert" has to conduct an audit to verify the mark and be able to perform the "record" of the property, with the added value, energy saving and lower CO_2 (carbon dioxide) emissions that this implies. This obligation is imposed by the implementation of the Directive in the following articles:
Article 17
Independent experts
Member States shall ensure that the energy performance certification of buildings and the inspection of heating systems and air-conditioning systems are carried out in an independent manner by qualified and/or accredited experts, whether operating in a self-employed capacity or employed by public bodies or private enterprises.
Experts shall be accredited taking into account their competence.
Member States shall make available to the public information on training and accreditations. Member States shall ensure that either regularly updated lists of qualified and/or accredited experts or regularly updated lists of accredited companies which offer the services of such experts are made available to the public.
Article 18
Independent control system
1. Member States shall ensure that independent control systems for energy performance certificates and reports on the inspection of heating and air-conditioning systems are established in accordance with Annex II. Member States may establish separate systems for the control of energy performance certificates and for the control of reports on the inspection of heating and air-conditioning systems. EN 18.6.2010 Official Journal of the European Union L 153/25.

2. The Member States may delegate the responsibilities for implementing the independent control systems.
Where the Member States decide to do so, they shall ensure that the independent control systems are implemented in compliance with Annex II.
3. Member States shall require the energy performance certificates and the inspection reports referred to in paragraph 1 to be made available to the competent authorities or bodies on request.
Therefore, the main question is:
“How can a protocol be implemented to check or control the energy efficiency or performance certification in existing buildings?”

2 DEVELOPING A PROTOCOL

How do we have to proceed to calculate the actual consumption of the building? In order to proceed with the development of the protocol, the actual consumption of the building must be calculated. How is this calculated?
The proposal to consider in this paper is based on a methodological system to measure or check the actual consumption in existing buildings instead of calculating it with models or programs. I propose the implementation of a method based on obtaining energy values by measurement or verification "in situ" (on site) and applying an appropriate methodology to obtain the consumption for heating, cooling, lighting, DHW (Domestic Hot Water) and miscellaneous uses of the building according to the same standard.
Stages of the process:
1. Establish the procedure for measuring or checking heating consumption.
2. Establish the procedure for measuring or checking cooling consumption.
3. Establish the procedure for measuring DHW (Domestic Hot Water) or checking its consumption.
4. Establish the procedure for measuring the electrical power for lighting and miscellaneous uses or checking its consumption.
5. Calculations with the approved, standarised national methods (computer programs).
6. Calibration with gas measure and recalculation and the rest equivalent emissions.
7. Final results.

3. METHOD

The next steps will be followed:

(i) Measure heating, cooling, DHW (Domestic Hot Water), miscellaneous uses and lighting (nº1-4 of control process).

This measure determines the conventional primary energy: Fossil fuel, natural gas, liquefied petroleum gases or electricity.

(ii) Using the standard methods the building’s energy efficiency can be calculated in order to obtain a certification qualification (nº 6 of control process).

We have to use the standard procedure approved that is applicable to each country to calculate the building’s (EU, 2011) official qualification in energy efficiency.

(iii) Calibration

Using the evacuated gas measurement procedure and adding up the rest equivalent emissions, "transfer or pass coefficients" can be calculated to obtain final emissions of CO_2 (carbon dioxide) and afterwards make a verification of the energy rating in the building certification. The purpose of development and use of the specific values obtained "case by case" and particularized transformation between energy consumed and emissions of CO_2 (carbon dioxide) from each building. Any case would have a specific transfer coefficient used to calculate the CO_2 emissions derived from the energy consumed in each building from the common national electricity mix and adding up its own emissions. This will be different in each study case because of the actual operating conditions according to the specifications of fuels, maintenance regime and technologies used. This way the real pass coefficients between CO_2 emissions can be obtained.

Gas emissions would be the sum of the building's emissions associated with the consumption of fossil fuels or other gases generated, and the emissions associated with the generation of electricity in power plants obtained from the electricity consumption from the national mix (nº 7 of control process) through the official transfer or pass coefficients.

The protocol will be addressed to various scenarios for individual housing. We have to measure or check the consumptions with the following criteria:

a. Occupied building. There is an easy calculation to obtain the total average consumption in energy units collecting domestic energy bills from at least the previous12 months.

b. Empty building. An actual test heating or cooling the house to the legal comfort conditions of temperature and humidity has to be conducted and then, following a cycle of continuous regime, obtain the total average consumption in energy units.

It is assumed that the house is equipped with heating, cooling, lighting and DHW systems as it will happen in the future (we can´t certify a house for any installation without determining it). Miscellaneous uses can be approached by standard uses after diversity maximum demand. We have to keep in mind the national standards for the following calculations:

- Analysis of the seasonal variations in energy consumption using properly models.
- Estimation of future consumption via an appropriate simulation.

4. COMMISSIONING

▪ Visual inspection of the building

This inspection consists of a visual verification of each of the equipments that will contain the inventory used in the study.

It has to be identify each of the equipments analysed (photo essay may be annexed), the reference of the installed equipment and operating data.

An indication of the main technical characteristics of each of the equipments contained in the inventory: brand, model, power consumption, etc.

Important note: performance data and use of the building cannot be estimated.

▪ Make detailed inventory of consumer equipment

Guidance for the elaboration of the detailed inventory of all the consumer equipment within the building:

✓ Heating and cooling systems have to be related in the inventory. Cooling consumption can be zero if it is not installed.

✓ For kitchen equipment, a simultaneity coefficient can be considered.

✓ Other electric appliances usually connected have to be taken into account.

✓ Equipment associated with renewable energy sources has to be included if installed (electric pumps and so on).

▪ Analysis of the seasonal variations in energy consumption

Evaluation of the causes of the differences in energy consumption between established periods (e.g. , consumption changes from summer to winter months due to the variability of the demand for air conditioning and heating systems).

▪ Estimation of future consumption. Establishment of baseline consumption by standard model.

A calculation is made taking as the baseline starting point the billing energy or measures taken and takes into account the weather as the main factor. In case there is some other factor that may modify the consumption it will also be taken into account for the calculation of the total building consumption.

▪ Performing "in situ" (on site) measurements of the various parameters of interest with measuring equipment such as:

- Manual or laser ruler
- Network analyzer
- Flue gas analyzer
- Voltmeter
- Photo camera
- Computer tools.

5. CONCLUSIONS

✓ The building certification process has to be a thorough work to offer all guarantees of its accuracy.
✓ The building control (audit in commissioning) is necessary to guarantee that the building certification is fairly accurate. If we are intending to save energy but the building certification is a routine with an uncertain result, the general objective of EPDB will be in doubt and probably fail.
✓ The exposed method could be valid for the building certification technician and the administration obliged to the necessary control. The certification could be audited in commissioning with a private or official control without any fear to be failed in the result if the method is adequate (ASIEPI, 2013).
✓ The building energy efficiency certification demands a control method to guarantee its usefulness.
✓ There is a difficult question: The cost of the certification.
✓ It is not possible to get a good work by a private technician if the fares are very low. Now most of the real state companies and private owners are trying to reduce prices because in the end this will be an additional cost to the property. Who pays for it?
✓ The administration could bill bad practices if the building energy certification control has failed in comparison with the certification results.
✓ What are the key ideas?:
❖ Quality work, user friendly but reliable
❖ Economically competitive
❖ Energy saving

The main conclusion is that we can´t sacrifice a quality work in the building's energy certification to be economically competitive, the aim we should never forget is that it is necessary to save energy and lower CO2 emissions. We have a useful tool to achieve this aim: "EPDB control (Brink, 2008)".

The absence of control may drive the European countries to lose the efficiency in all the EPDB implementation process. If we intend to save energy and lower the CO2 emissions we have to be very straight with the proceedings.

The first steps of the implementation of the new RD 235/2013 and related norms (CTE and RITE) (Spain, 2013) in Spain are being a little confusing because of the insufficient care when gathering data from existing buildings. There is a bad practise effect when applying the new norm mixed with a great conflict of interests in a crisis sector at this moment. The several agents involved are really wrong about the meaning of the building energy certification because most of the people think it is a question of bureaucracy. This is an unsolved question in Spain as well as in other European countries.

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Towards adaptive control systems: Bayesian models for energy efficiency

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ABSTRACT: The development of a new class of adaptive control systems, behaving consistently in changing environments, is the main objective of this research. The term adaptive means that the building control system is able to interpret the sensed data (both indoor and environmental) and to forecast future states; to evolve its policies as the operating context evolves and to learn from its history. This contribution proposes a methodological framework for the development of adaptive and predictive of control systems, based on Bayesian Networks. First results concerning the development Bayesian Networks for the optimal control of buildings are discussed.

1 INTRODUCTION

The concept of “Smart Home” which is able to get the most from its environment reducing the energy consumptions was suggested about twenty years ago (Smith 1987). Despite that, the large majority of present building energy control systems still operate on the basis of homeostatic short-term feed-back mechanisms. Since the equipment and systems providing thermal comfort and indoor air quality for commercial buildings consume 42% of the total energy used in buildings (Gregor et al. 2005), the impact of any optimizations of the control mechanisms will have a relevant impact on the overall energy balance. Some studies (Oldewurtel et al. 2010) show that the use of predictive control strategies for the control of the building interior climate provides an energy saving of more than 40% with regard to traditional short term feedback.

The recent development of new building components and technologies (e.g. Active Building Envelope, Variable Transmittance Envelopes, Radiant Floors using Phase Change Materials for cooling, etc.) as well as the new generation of local renewable energy sources and the smart energy grid provide the new necessary framework for the development of dynamic adaptive control policies of the building behavior. The new smart home protocols will allow the home sub-systems to communicate each other and with the energy grid, thereby enabling autonomous and/or remote control of the various home systems simultaneously, in pre-programmed scenarios or dynamical operating modes. Recently, noteworthy prototypical examples of smart buildings have been built (i.e. InHouse project Dimitrov et al. 2007, Naroska et al. 2007).

Nevertheless many issues are still open in the design of the control policies and more in general of the control system architecture. They mostly concern the ability to adapt to the changing environments either external (i.e. the weather and the surroundings) or internal (i.e. the end user wishes and their behavior). Seasonal and short term weather fluctuations around its historical average data have become remarkably more significant in the last decade. The predicting capability of control systems, that are usually based on historical data, should be enforced by providing continuous learning mechanisms that seamlessly adapt the predictor to weighted combinations of past and present trends. Concerning the internal environment, the simple automatic switching of equipment can be felt as a nuisance by the occupants. Automatic switching is well accepted when it is regular and predictable, but can be very bothering when it surprises the occupants, because people generally like to have control over their own. Moreover, occupants want to manage their comfort and the building efficiency, and to be assisted in choosing among the possible management scenarios. Finally, technology has to take into account the possible failure modes of the building automation equipment (e.g. the temperature sensor that starts to lose its accuracy, the motors opening the window or in charge of ventilation will jam, etc.).

The development of a new class of adaptive control systems, behaving consistently and adaptively in changing environments is the topic of this research. This paper proposes a methodological framework for the development of this class of control systems, based on Bayesian Networks, and provides first results concerning the development Bayesian Networks for the optimal control of buildings. Section 2 briefly introduces the main features of Bayesian Networks. Section 3 discusses application of Bayesian Networks to the construction of predictive control models. Finally some conclusions and further remarks are given in section 4.

2 BAYESIAN NETWORKS FOR DYNAMIC SYSTEM MODELING

A Bayesian Network (BN) is a directed acyclic graph, that represents, through directed arcs, the causal dependencies among a set of random variables denoted by its nodes. Random variables can be either symbolic or numerical, and in the last case continuous or discretized. Each causal link, connecting for example nodes X and Y to Z, is represented by means of a conditional probability table (CPT), that quantifies the effects that the observed evidences on values of nodes X and Y have on the probability distribution of Z. Therefore a BN performs probabilistic inferences by computing the posterior probability distribution of the set of query variables (i.e. Z in our example), when the evidence on other variable values are assigned (i.e. X and Y) (Neapolitan, 2004).

Modeling whatever systems by means of BN involves therefore the definition of the node set, of their causal links and the calculation of the CPTs. In many practical problems of physical modeling neither the topology of the BN nor the CPTs can be easily determined. For this reason several methods for learning the graphical structure (i.e. structural learning) and estimating probabilities from data (i.e. EM learning) have been developed.

The modeling of the system dynamics, like for example the building thermal behavior, through BN requires a further specification of the BN topology. In this case both the causal links representing the instantaneous system behavior (i.e. the internal state) and the links that regulate the temporal transition among different states must be specified. This kind of BN is known as Dynamic Bayesian Networks (DBN) (West et al. 2007). In order to keep the complexity of the representation manageable, it is necessary to make two assumption in relation to the dynamic aspects of the representation. In the following we will assume that the processes are stationary, that is, processes that are regulated by laws that don’t change during time. In terms of the Bayesian representation, the hypothesis of stationary process means that the network structure is the same for all states. In addition, we will consider only Markovian processes. In other words we will assume that each state is affected only by a finite number of previous states.

For example, Figure 1 depicts a DBN implementing a general weather dynamic model that can be used for short-range local prediction. The DBN is built around an instantaneous weather model that is highlighted by the dashed rectangle. The instantaneous weather model is made of four random variables, namely: W_m0, T_m0, H_m0, R_m0, that respectively represent the wind speed, the air temperature, the relative humidity and the solar radiation measured by a weather station. The _m0 postfix means that these variables are referred to time 0. This network represents the instantaneous relationships occurring among the four climatic variables. In this case the network links have been learned by the weather data records of the weather station. In order to take into account the time dynamic of the weather evolution, so that weather predictions can be performed, it is necessary to relate different models, like the one for T=0, referring to different time shots. In the weather predictor of Figure 1 the same structure has been repeated for time T=-2h (i.e. two hours in advance) and time T=+5h. The rest of the variables represent a Markov chain of order 2 for each of the four variables that is extended up to T=-8h.

This predictor can be used to estimate the probability distributions of the variables of the weather model at time T=+5h once the evidence of the measured values in the previous eight hours have been observed in the respective nodes.

Learning dynamic weather models like the one of Figure 1 requires that the structure of the data set is adapted to the network structure. Once the model has been determined through structural learning and EM learning, the BN technology provides a continuous updating mechanisms that allows for the adaptation of the CPTs on the basis of the new measurements. This continuous learning mechanism can be also modulated by introducing fading effects on the data set, so that newer measurements can be considered more relevant than older ones. Therefore any predictive models, built by means of BNs, are able to adapt their predictions by taking care of new observations in a very flexible way.

The above weather predictor can be considered as one of the many sub-models composing an integrated building-environmental model that is able to support dynamic control. The next section will detail the development steps of a weather predictor and of a simple model of a building thermal dynamic, and will discuss their integration for the predictive control of the building thermal regimes.

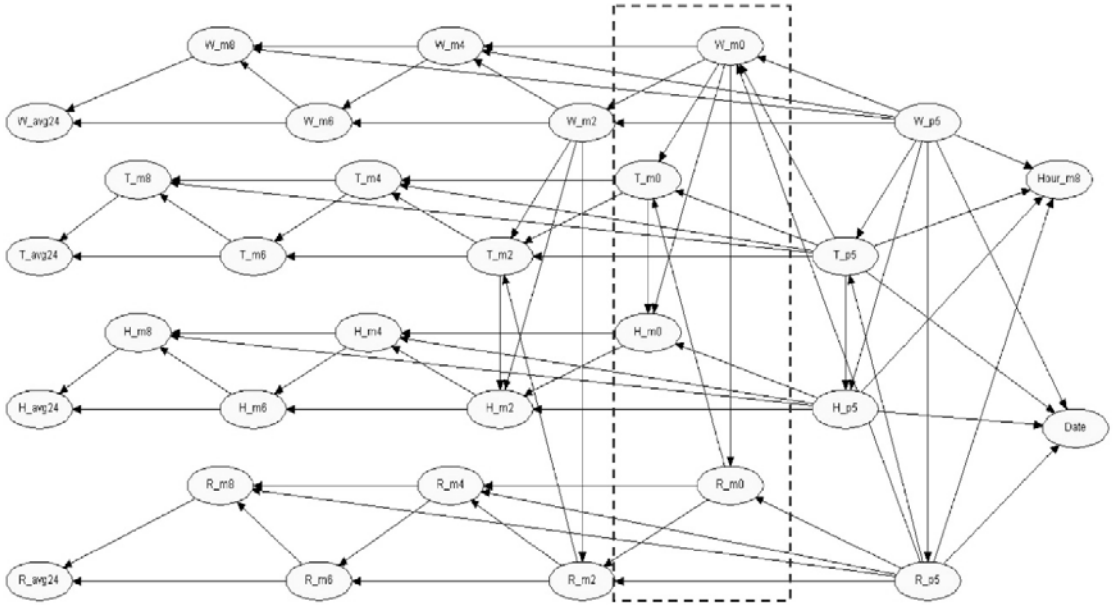

Figure 1. Dynamic Bayesian Network for short range local weather prediction.

3 BAYESIAN PREDICTIVE CONTROL MODELS

3.1 *The development of a weather predictor*

The main requirement of a weather model for building control is that it should be able to provide, with a good accuracy, the local trend of the main weather variables for a time period comparable to the time constants of the building (3-6 hours). The steps followed for the construction of the weather model through BNs are:

- Data Gathering: A relevant amount of data (10 years sampled every hour) has been necessary to produce reliable forecasts including seasonally atypical situations.
- Parameter identification: The identification of the relevant parameters have been based on domain knowledge. As we have already mentioned, we have identified four meaningful variables: T=External Temperature, H=Relative Humidity, W=Wind speed, R=Direct solar radiation (see Fig.1). Once the variables were identified, a discretization of their domains in suitable intervals was carried out.
- Structure identification: The definition of network structure was iteratively conducted by alternating structural learning phases with hand-made adaptations, carried out on the basis of domain knowledge. The analysis of the dynamic model for each variables, pointed out that a second-order Markov process provides the best correlation in the dynamic part of the model. A noteworthy improvement of the overall performance in prediction was obtained through the introduction of the nodes related to the average value of the variables in the 24 hours before the time of the first recorded datum (T_avg24),

and the introduction of the nodes related to date and time of the day. This allowed the minimization of the uncertainty due to seasonal and daily temperature range. Finally the quantification of the conditional dependences among the variables was achieved via statistical learning algorithm (EM Learning) (De Grassi et al. 2008).

- Validation of results: The model was validated using a data set related to 1 year of recording that was not formerly provided to the training database. The results were compared with the outcome obtained by means of other proven methods. In particular a deterministic Autoregressive Recursive Moving Average (ARMA) model with order 64 and 5 hour of prediction time was used for each of the 4 variables with the same methodology used in the Great Energy Predictor Shootout 2 (Florita et al. 2009). The error statistics of the estimation of the 4 variables with both methods are reported in Table 1. The results are comparable for the two models, with an average yearly error of the same order of magnitude. The relatively high absolute value of the error for both models was due to the climate zone chosen for the assessment, characterized by daily thermal excursions higher than 20 C°.

Table 1. Comparison of BN and ARMA predictor outcomes.

	Temperature [C°]		Solar Radiation [W/m2]		Wind Speed [m/s]		Relative Humidity [%]	
	ARMA	B.N.	ARMA	B.N.	ARMA	B.N.	ARMA	B.N.
Avg. Error	1.9	2.2	90.6	61.6	1.5	1.9	8.5	11.2
St. Deviation	1.8	2.1	8.1	10.3	1.2	1.6	8.1	10.3

3.2 *The predictive building control model*

The building control structure has been defined using a simplified version of the weather predictor discussed above (i.e. limiting the variables to Air Temperature and Solar Radiation) and introducing visual and thermal comfort and energy need parameters.

The overall building model CPTs were derived from a data-set produced by means of simulations carried out with Energy+ software and processed thus obtaining the hourly energetic behaviour of the prototype (Fig.2). For simplicity a one room air conditioned building with only one window placed in the east side and provided with an adjustable angle shades was used.

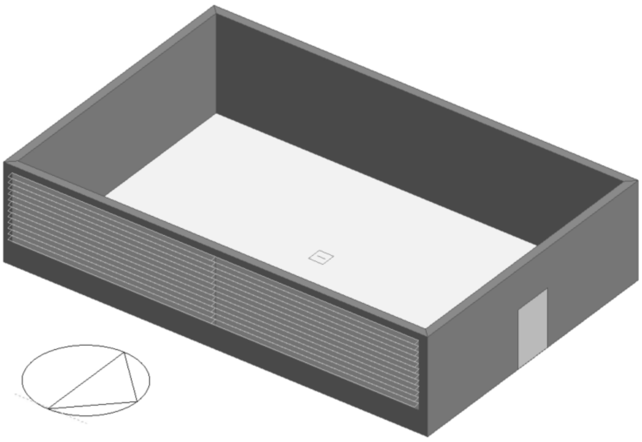

Figure 2. Building Prototype.

A brightness detector, for the control of the visual comfort conditions, has been placed in the center of the room at 80 cm height. The simulations were performed in the summer season (from April to September), changing both the set-point temperature (operative comfort temperature) of the HVAC and the angle of opening of the shades. The resulting data set was arranged and used to feed Bayesian Network structural and EM learning algorithm. More specifically the causal relationships linking comfort and consumption parameters to the weather model were determined by iteratively adapting structural learning outcomes on the basis of domain knowledge.

To limit computational complexity, the time-step considered for this network was reduced to 3h. Figure 3 shows an application of the resulting BN to the control of the building energy consumption through the temporal variation of the opening angle of the shades. Once the date and current time were set (i.e. 7 o'clock in July) by blocking the nodes Hour = 7 and Date = lug, it is possible to set the measured values of the external weather variables: External Temperature and Solar Radiation at time T=0 (the values of the variables are Te_0= 22.02 C° and SR_0= 354.42 W/m2).The BN is now able to predict the evolution of the weather conditions in the following time-steps, specifying for each weather variable both the expected value μ and the standard deviation σ. In this case the values of these parameters are for node Te_3 (μ= 24.81 C°, σ2= 1.45) for node SR_3 (μ= 750.18W/m2, σ2= 8701.54) for node Te_6 (μ= 25.3 C°, σ2= 0.92) and for node SR_6 (μ= 767.2W/m2, σ2= 18517.96).

Then it is possible to set the measured parameters related to internal conditions. The values are: for the operative temperature Top_0= 23.98 C°, for the internal brightness Rad_0= 127.54 lux and for the instantaneous consumption En_0= 1.26 KWh. Furthermore at time T=0 the shades are completely open Sh_0= 90°.

After the setting-up of the environmental conditions and of the building internal status, the shades angle control policy can be deduced by imposing the desired comfort and consumption levels as is shown in Figure 4.

They can be fixed by observing the internal comfort and energy consumption parameters up to the prediction horizon: operative temperatures Top_3 = Top_6 = 24 C°, the internal brightness in the range of comfort Rad_3= Rad_6 between 250 and 500 lux, and the energy need in medium-low consumption level En_3 = En_6, between 0,5 and 1 KWh. At this point the BN has enough information to provide a rather sharp control policy of the shades angle in the following 3 and 6 hours. In that case the network shows that in other to get the desired levels of comfort and consumption, the value of the shades angle shall be in the range between 45 and 90 degrees, as shown in nodes Sh_3, Sh_6.

The advantages offered by Integrated Bayesian Control systems with respect to auto regressive predictors and short-term feed-back mechanism are numerous. In terms of the information provided, for each variable the net gives both its expected value and its standard deviation. This can be used to provide an immediate feedback of the quality of the prediction. Large unfocused distributions (i.e. elevated standard deviation of the estimated variable), are usually symptoms of a poorly behaving model, while sharp focused ones are sign of accurate predictions. Furthermore the explicit structure of the model and the possibility of performing sensibility analysis for any given configurations of its parameters can be used to clearly explain the model behavior and to support the evaluation of alternatives through what-if analysis. The limits posed by the procedure lie essentially in the error deriving from the discretization of the variable domains, in the large memory requirement even for relatively small models and eventually in the limits present in the training data set. The net is actually able to foretell the policy of control on the basis of the learned data. If a weather condition that is not contained in the training data set occurs, then the net will give a fuzzy estimation (large unfocused distribution). However, the system is able to learn from its history so that its response can be continuously adapted to the evolved operating context, providing more and more accurate predictions.

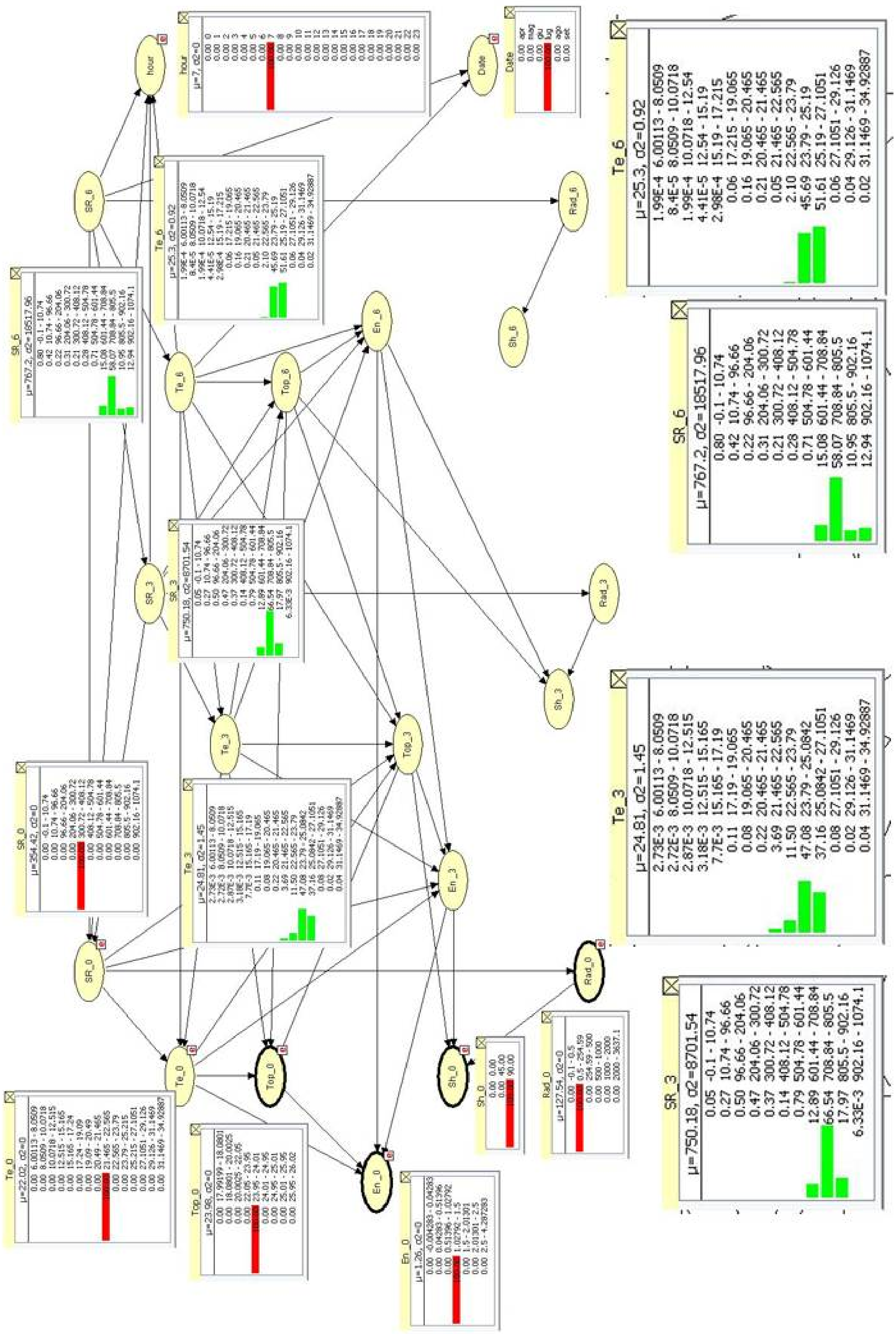

Figure 3. Dynamic Bayesian Network for predicting the policies of the control of the buildings.

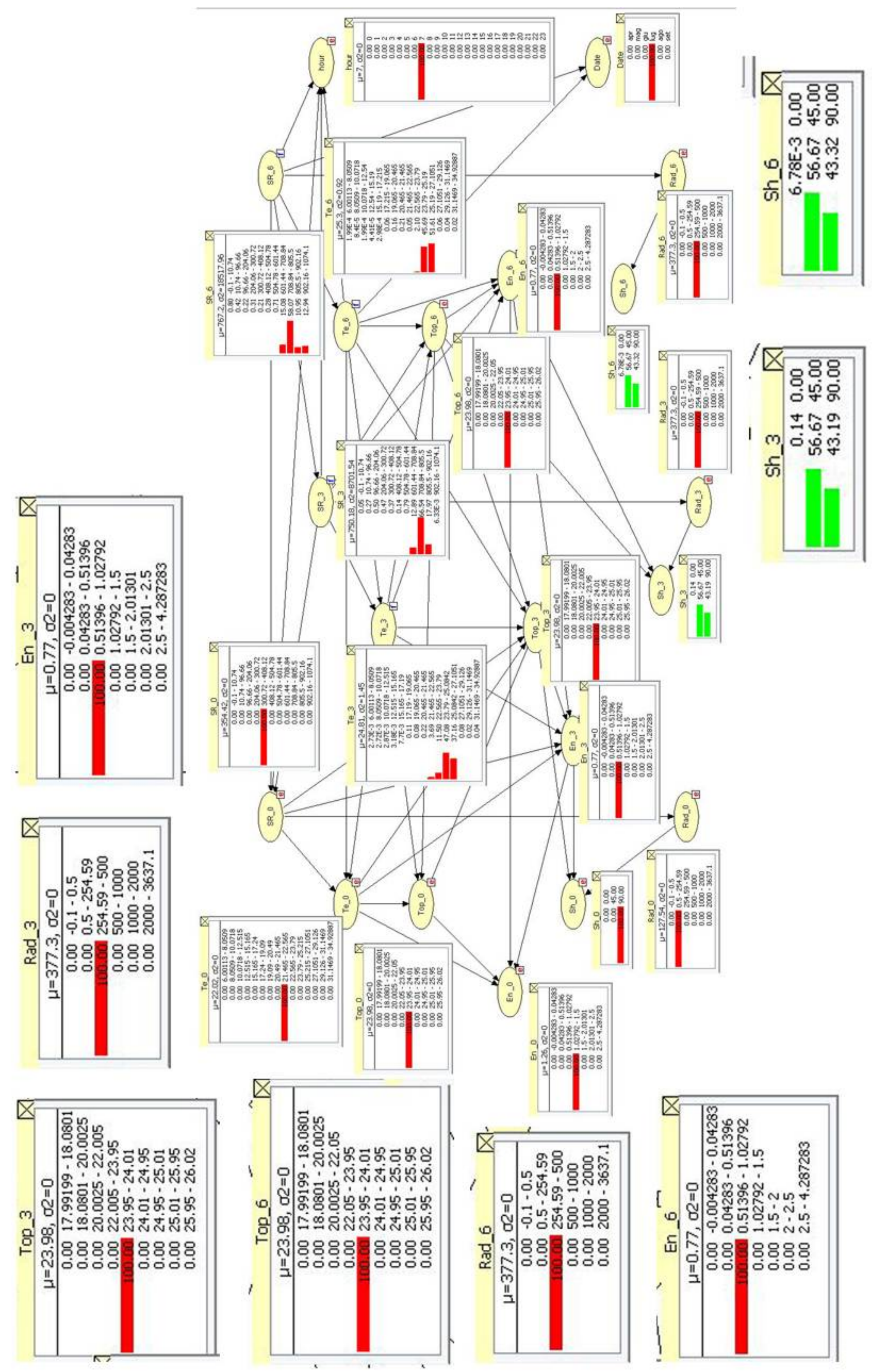

Figure 4. Dynamic Bayesian Network for predicting the policies of the control of the buildings.

4 CONCLUSIONS

The present paper addressed the development of a methodology aimed at defining predictive control models of buildings. The most important aspects and some limits of this procedure have been illustrated through one simple example. Forthcoming developments will include the using of continuous chance nodes that will minimize the discretization error and will limit the computational space complexity.

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Sustainable Energy Management for Underground Stations: Lighting Upgrade

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ABSTRACT: Underground transportation systems are big energy consumers and have significant impacts at a regional scale. One third of the networks' energy is required for operating metro stations. A 5% saving in non-traction electricity consumption is equivalent to the electricity consumed in more than 340 households. The EU-funded project SEAM4US (Sustainable Energy Management for Underground Stations) will create a system for optimized energy management that, acquiring user and environmental models through a sensor network, will effectively reduce the energy consumption of the station by 5% - 10% in a real-world pilot conditions, a metro station in Barcelona. This paper reports the preliminary study developed in order to estimate the possibility of reduction of lighting consumption thanks to the retrofitting of the lighting system and the installation of controls. After an analysis of the current system, lighting performance models were developed and a scenario analysis performed, for investigating the saving potentials achievable.

1 INTRODUCTION

1.1 *Overview*

The role of lighting systems is to provide adequate visual conditions for human activities that must carried out efficiently and comfortably. Public buildings require specific care when designing, purchasing, commissioning and maintaining lighting systems. On the other and, the Energy Performance of Buildings Directive (EPBD) strongly recommends to produce and retrofit buildings to near-zero energy use levels. Lighting is one area where energy savings are possible at reasonable cost in new buildings as well as in retrofit projects (Dubois et al. 2011). (Enkvist et al. 2007) indicated that investments in energy-efficient lighting is one of the most cost-effective ways to reduce CO2 emissions.

Lighting is a large and rapidly growing source of energy demand and greenhouse gas emissions. In 2005 grid-based electricity consumption for indoor lighting was estimated at about 17.5% of the total global electricity consumption (IEA 2010). Indoor lighting accounts for a significant part of electricity consumption in buildings: in Europe office buildings use 50% of their total electricity consumption for lighting, while the share of electricity for lighting is 20-30% in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings (Volpe 2012). Furthermore, the heat produced by lighting represents a significant fraction of the cooling load in many offices contributing to further indirect consumption of electricity.

In terms of environmental impact, the key factor is the use phase. Energy consumption and associated Greenhouse Gas (GHG) emissions can reach amounts up 90% depending on the lamp type (ELCFED 2013).

Reducing electricity consumption of lighting during the use phase includes mainly two complementary phases:

- retrofitting the lighting equipment to a more efficient one,

- enhancing the lighting control policy and system.

1.2 *Lighting Energy Saving in Public Buildings*

For public buildings, these two steps differ highly in terms of costs, much more than for any other building typology. Retrofitting of the equipment of a public building is usually a very expensive strategy, often requiring major capital investments. On the contrary, the use of advanced control system can lead to great savings requiring minor investment costs.

Regarding the lighting equipment, in most public buildings still have lighting systems with fluorescent tubes, usually T8. Fluorescent tubes are cheap and reliable; they tend to be less glaring than more compact, brighter sources; they can be switched and dimmed readily; can be quite efficient, with good color rendering (e.g. T5). Unfortunately, not every lighting installations can be retrofitted with more efficient lamp types. T5 fluorescent lamps need an appropriate luminaire and they cannot replace T8 lamps in older luminaires without special adaptors, and so in many cases this will require replacement of the whole installation: luminaire, lamp and ballast. If the building needs the replacement of the existing indoor lighting stock, Light Emitting Diode (LED) lamps are now a valuable alternative in terms of energy efficiency and quality of light. LEDs are directional sources so are ideal for display or accent lighting, but can also be incorporated in general lighting fittings. Within a few years, it is expected that the efficacies of LED chips will rise up to 200 lm/W, so lower wattage lamps may then be able to provide the required amounts of light. Concerning the lighting systems, LED based systems can be more flexibly controlled in terms of beam angle, light color, dimming or frequent switching (EU DG ENV 2011). In general, replacing existing lamps with energy efficient lamps gives saving on maintenance costs as well as on energy consumed: maintenance staff costs can be drastically reduced as the lamp life is longer and it has not to be replaced.

Energy saving due to optimized control (i.e. that regulate the dimming level) depends on numerous factors including the application, site orientation and occupation, building design, interior reflectance, occupant behavior, tuning and configuration during installation, commissioning. These concurrent factors make the overall energy savings less easy to predict. Many type of controls are possible, from the manually activated systems to the automatically modulated lighting on the basis of occupancy demand and/or natural daylight available. (Williams et al. 2011) estimates average lighting energy savings potential of 24 percent for occupancy, 28 percent for daylighting, 31 percent for personal tuning, 36 percent for institutional tuning, and 38 percent for multiple approaches. Other studies state that using optimized automatic controls will save 30-40% and can be highly cost effective (Littlefair 2006). In fact, in a new installation the cost of installing advanced lighting controls may be the same as that of a conventional manual control system, while they have a typical payback periods of 2-4 years when retrofit to an existing installation (EU DG Env. 2011).

Summarizing, the optimized control is a very promising candidate to sustainable investments for the energy efficiency of public buildings. The US National Electrical Manufacturers Association (NEMA) has argued that controls have greater potential for energy savings in major applications than do increases in source efficacies (DOE 2011).

1.3 *Lighting Retrofit Strategies in SEAM4US*

Underground transportation systems are big energy consumers and have significant impacts at a regional scale. Approximately 30% of the total electrical power is needed for non-traction subsystem, meaning mainly the subsystems in the station buildings: air-conditioning and lighting. On average, a subway station consumes 50 times more energy than a residential building. Considering that usually a single institution manages hundreds of stations, it emerges clearly that energy efficiency in subway stations involves great absolute savings, even with small percentage savings. The EU-funded project SEAM4US (Sustainable Energy Management for Underground Stations) is aimed at creating a system for optimized integrated energy management and developing a decision support system to drive mid-term investments. SEAM4US integrates additional energy metering and sensor-actuator networks with the existing systems (e.g. surveillance, passenger information and train scheduling), by means of middleware as abstraction layer, to acquire grounded user, environmental and scheduling data (Ansuini et al. 2012). The data set update and enable a set of adaptive energy consumption and environmental models to control proactively and optimally the metro stations.

In relation to lighting, even if the main purpose of the SEAM4US project is to save energy by improved management, rather than by applying expensive retrofit measures, in the first phase of the project, saving potentials must be investigated both for lighting equipment updating and for lighting control inclusion. Specifically, the SEAM4US project is being developing a referring to a real-world pilot in the Passeig de Gracia – Line 3 (PdG-L3) station, managed by TMB – Transports Metropolitans de Barcelona. One of the project objectives is to transfer results to other subway stations. Thus it was important to identify saving potentials not only in relation to a specific lighting system, but also considering alternative ones. The comparison among scenarios involving different lighting technologies was based on the analysis of the platform, since it is the subway stations' most critical space, and usually involves the greater part of the fixtures used in the station. The current lighting system is briefly described in Section 2. A model of the actual state was developed based on technical information and survey data, and it is used as the baseline for the scenario analysis. The different scenarios considered for technology upgrading and control are reported in sections 3 and 4. Finally, section 5 presents the main results achieved

2 CURRENT LIGHTING SYSTEM

2.1 *Actual Lighting System*

In the public areas of the PdG-L3 station, there are basically 3 types of fixtures, and one type of emergency light (Fig. 1). Almost all the fixtures use T8 fluorescent tubes of 36 W. Other lamps can be found within private dependencies, but since they represent a very small amount of the total expenditure, they have not been taken into account in detail. All lamps use standard electronic ballasts. Table 1 shows that most part of the lamps are in the platform, that , consequently, the space that has been used for the scenario analysis.

Table 1. Main data for PdG –Line 3 station.

	Platform	Halls	Corridors / Stairs	Private Rooms	Total
Number of lamps	264	97	170	18	549
Power [W]	9504	3492	6120	570	19686
Power [%]	48%	18%	31%	3%	100%

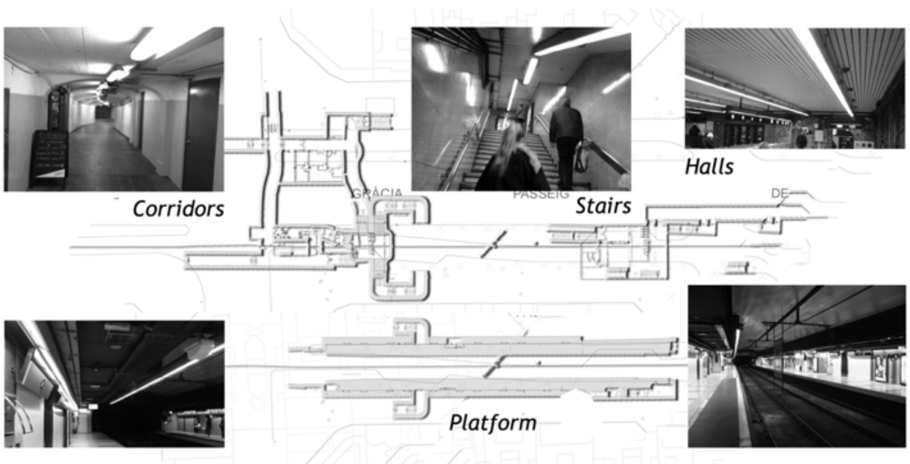

Figure 1. Overview of the lighting system in different spaces of PdG-L3 station [lux].

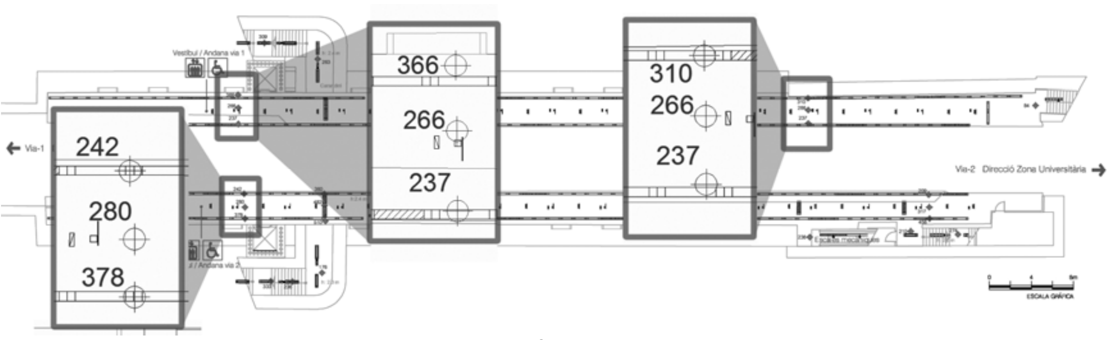

Figure 2. Lighting Survey in PL3: measures used for computing average illuminance [lux].

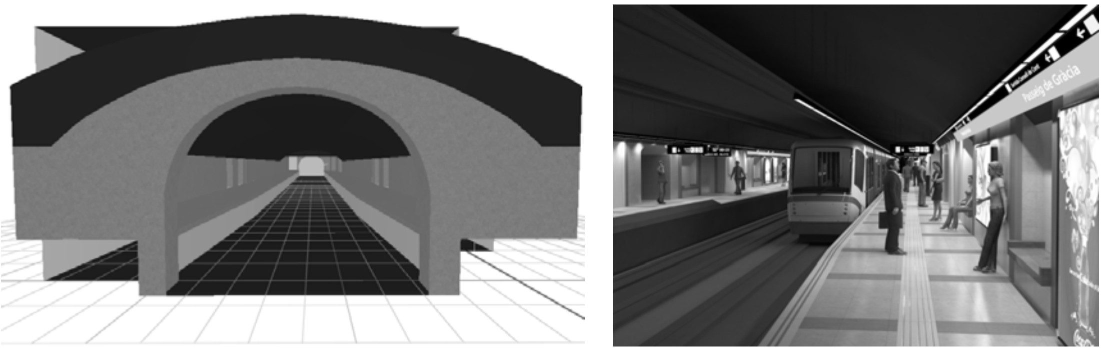

Figure 3. PL3 Model, Scenario: T8 – No Control. 3D image of the model and a photorealistic rendering.

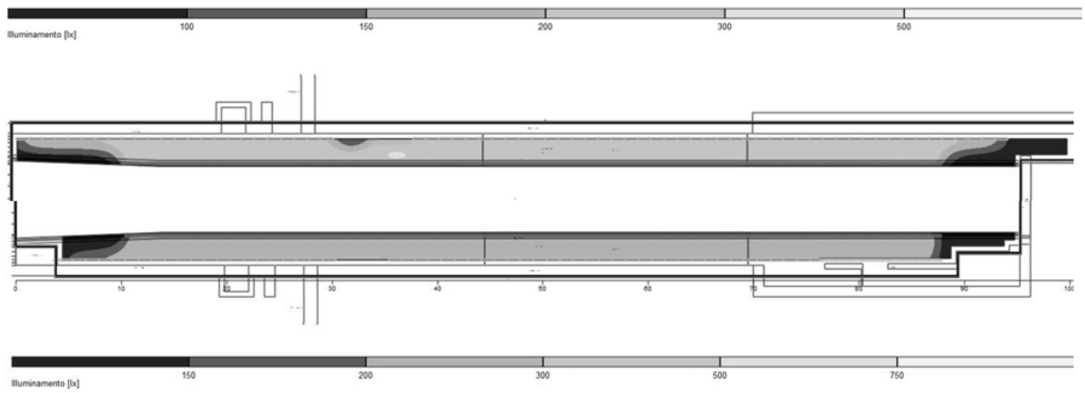

Figure 4. PL3 Model, Scenario: T8 – No Control. Map illuminance levels on the floor.

On the platform (PL3), there are two continuous lines of lamps, one near the wall, illuminating the information posters and signs and, another, above the edge of the platform (Fig. 2). The fixture used is produced by STI, and uses two TL8 36W fluorescent tubes, disposed longitudinally in line (Table 3).

2.2 *Main data from the Lighting Survey*

A performance survey was carried out in March 2012 to map current illuminance levels provided by the lighting installation.

According to current regulations (EN 12464-1:2003), minimum illuminance level requirements vary depending on the use of the space. Hence, the maximum required is 300 lux at ground level in ticketing zones (selling and validating) and the minimum required is 150 lux at ground level for most of the remaining spaces (stairs, corridors, ramps, etc.). In the platform, 200 lux have to be granted on the edge, while 150 lux are required as average.

The survey revealed that current illuminance distribution throughout the station is not uniform, even in zones that share luminary types and distribution, along with surface materials. As an example, a comparison between two corridors, both using the same fixtures, revealed a difference of almost +50% (202 lux versus 300 lux). In the platform, 9 point measurements along the platform were considered sufficient for computing the average illuminance in the platform, resulting as 287 lux (+ 90% than average level required by regulation).

2.3 *Actual State Model*

A model of the actual state was developed in the Relux ® Simulation Environment and preliminarily calibrated with the survey data. This model was used for achieving a reference simulation in the comparison and as simulation context for the alternative lighting systems to be investigated. Main assumptions done for this model are:

- Lamp and luminaires used: unfortunately, in the Relux model, the luminaires used are not exactly the products deployed, as the brand did not develop compatible software files. Among the products available in the Relux repositories, 3Brothers® products (Table 2) were identified as being the most similar to the installed appliances.
- Reflectance factors for the surfaces of the indoor environment : hypothesized with expert advice and confirmed in the preliminary model calibration
- Maintenance Factor: preliminary model calibration for the platform fixed MF = 0.8.

Figure 6-14 reports an image of the actual state model of the platform in PdG-L3. Figure 3 shows a 3D image of the model and a photorealistic rendering while Figure 4 shows the illuminance levels on the floor. A typical task area (red rectangle) was used for the analysis of the meaningful lighting performance parameters, reported in Table 4.

3 LIGHTING TECHNOLOGY RETROFIT

Lighting design is the result of ballast/lamp/fixture combinations that will maximize efficiency while balancing the lighting requirements specified. At this stage, only macroscopic alternatives were considered. As electronic ballasts are already used in the station, possible improvements can be achieved by maximizing the efficiency of light sources and luminaries.

Regarding the lamps, realistic constraints limit the options to three lighting technologies: keeping current T8, or switching to state of the art fluorescent (T5) or LED. Intervention would be needed in any case: T8 would need new ballasts and wiring amongst them for control purposes, and T5 or LED lighting would require new fixtures on top of the control system.

T5 tubular lamps are designed to run hotter than the T8 lamps, giving improved efficiency in enclosed luminaires. Compared with T8 lamps they are shorter in length, allowing them to be used in fittings that fit into smaller ceiling grids, and use smaller sockets. Luminaires designed specifically for the T5 lamp tend to be more efficient because of the reduced source size. For all these reasons, T5 lamps cannot be simply retrofit into existing T8 luminaires without a special conversion kit (Benya et al. 2011)

Table 2. Main data of the lighting fixtures used in the models.

		T8	T5	LED
Manufacturer		3Brothers	iGuzzini	LightLED
ID CODE		17320-FL	Linealuce 7864	Lexell Slim V8 NW
Lamp type		FL T26 G13	T5 G5 LFL	LED NW
Lamp power	W	36	28	14
Total luminous flux (for T=4000k)	lm	3450	2600	1495
Length	mm	1238	1238	1000
Width	mm	170	75	30
Height	mm	97	76	76

LEDs are expected to play the main role in the future of efficient lighting, even if so far, they are not very spread in the market. The vast majority of public buildings uses fluorescent lighting, which is less easy to control and dim than is the emerging LED lighting. LEDs are an inherently low-voltage source that can be more cost-effectively dimmed over a wider range than can current technologies and are therefore more amenable to control strategies such as personal tuning. LEDs will not only allow provide additional energy savings, but will also have the potential to enhance occupant comfort by improving control granularity, by allowing better occupant access to local lighting systems, and by the ability to control the light source spectrum according to automatic input and user preferences (Williams et al. 2012).

Finally, concerning the fixtures, as a universe of different products is available today on the market, the criterion used in this study was very operational: simulation were done by using fixtures produced by the prospective associate partners to the project.

In fact, contacts were established with two enterprises of the lighting sector in the first year. These two potential partners offered their contribution in supporting the definition of possible retrofit scenarios for some typical spaces of the pilot station.

Finally, three technological scenarios were splitted (details in Table 2):

- Current T8 fluorescent tubes (17320-FL-T8 36 W by 3Brothers);
- Retrofitting with T5 Fluorescent tubes (LineaLuce FL-T5 28W by iGuzzini);
- Retrofitting with LED technologies (Lexell Slim V8 NW 14 W by LightLED).

The development of the alternative scenarios and related models was based on the assumption of keeping the same lighting layout concept: for each platform, the same amount and position of the actual lamps, placed along two lines, one on the edge and one along the wall. In order to have comparable models and results, the same Reflectance Factors and Maintenance Factor (0.8), were kept.

Two different luminous fluxes were considered, depending on the color temperature performed. In fact, regulations require 6000K on the edge of platforms, while 4000K is sufficient elsewhere.

Table 3 reports a summary of the number of lamps considered in the T5 and LED scenario, and the related installed powers. Meaningful performance results are reported in Table 4.

Table 3. Scenarios in platform: lamps, dimming coefficient and power main data.

Setting			PL3 side 1		PL3 side 2		Total PL3		Total PL3
			edge	wall	edge	wall	edge	wall	
Lamp Number			62	71	62	69	124	140	264
T8	Current State	Power	2232	2556	2232	2484	4464	5040	9504
	Control	Dimming coefficient	0.78	0.375	0.78	0.375			
		Power	1741	959	1741	932	3482	1890	5372
T5	Retrofit	Power	1736	1988	1736	1932	3472	3920	7392
	Control	Dimming coefficient	0.75	0.319	0.75	0.319			
		Power	1302	634	1302	616	2604	1254	3854
LED	Retrofit	Power	868	994	868	966	1736	1960	3696
	Control	Dimming coefficient	0.75	0.319	0.75	0.319			
		Power	693	388	694	377	1389	764	2153

4 LIGHTING CONTROL

The lighting control system being considered is DALI (Digital Addressable Lighting Interface), a protocol backed by the lighting industry, fully described in IEC standard 62386 (2009). It was designed with the aim of updating current analog dimming controls based on 1-10V control interfaces, while introducing computer-based control systems. The DALI control system will have an interface with the general SEAM4US control system, that will generate the control policies, on the basis of the manager constraints, regulations and models. At this stage, the dynamic control policy was not yet defined, since it depends on detailed occupancy data that are not yet available. Thus, simulation-based investigations were done for the three scenarios (actual T8, new T5, new LED), with the aim of defining the maximum saving potentials related to control. An iterative process was used, varying the luminous flux of the lamps in the model and simulating it, until the minimum levels of illuminance and uniformity (allowed by regulation) were reached. Specifically, the illuminance levels (Eavg > 200 lux on the edge; Eavg > 150 lux in general) and the uniformity (Emin/Emax > 0.5) were checked on a restricted task area, avoiding the anomalous point of the platform.

This led to a forecast regarding the highest applicable dimming coefficients. As the existing standard establishes different levels (for the edge and for the overall floor), two dimming coefficient were obtained, one for lamps on the edge and one for those along the wall (Table 3). Once these coefficients were identified, the related used power was computed, without considering ballast efficiency. The performance results are reported in Table 4.

5 MAIN RESULTS AND DISCUSSION

The scenario analysis finally resulted in six scenarios, only three of them considering a lighting control system, as described in section 4.

Table 4 compares them through the most meaningful lighting performance data: illuminance levels on the floor and uniformity.

Table 5 compares the three lighting technologies (in lines) and the two efficiency strategies (equipment retrofit and control, in columns) through the estimation of used power resulting from each scenarios, and related savings.

Table 4. Comparison between simulation results for T8, T5 and LED scenarios: Lighting Performance.

Setting		No Control			Control		
		Actual State	Equipment Retrofit				
		T8	T5	LED	T8	T5	LED
Illuminance	E_{avg}	272	348	321	190	176	186
E [lux]	E_{min}	221	287	285	142	114	144
	E_{max}	290	386	336	213	213	207
Uniformity		0.76	0.74	0.84	0.66	0.53	0.69

Table 5. Comparison between T8, T5 and LED scenarios: Estimated Power and related savings

Setting	No Control		Maximum Control		Retrofit+Control
	Power	Saving	Power	Control Saving	Total Saving
	W	%	W	%	%
FL T8 36W	9504		5372	43.5	43.5
FL T5 28W	7392		3854	47.9	59.4
Saving T8-T5	*2112*	*22.2*	*1518*	*28.2*	
LED 14W	3696		2153	41.7	77.3
Saving T8-LED	*5808*	*61.1*	*3219*	*59.9*	

The main considerations are:

- equipment retrofit from T8 to T5 or LED is very effective, both in terms of lighting performance and energy efficiency, nevertheless while upgrading to T5 gives 22.2% of saving, upgrading to LED gives 61.1% of savings ;
- obviously, the integration of control is very effective in terms of energy saving, but produces lower illuminance levels, as it is conceived on the basis of minimum regulation requirements;
- comparing the control scenarios it emerges that the amount of saving that can be related to the introduction of a control system is quite constant (42-48%) and only slightly dependent on the technology adopted and the specific products: control seems to be most effective for T5, and this is due to the fact that the T5 “no-control” scenario had the higher illuminance levels, thus it was the most far from the regulation level;
- considering the total savings, achievable in this case between the current situation (T8, no control) and the combined solutions (Retrofit+Control) the highest savings are achievable with LED lamps (77.3%), but also the savings achievable with T5 (59.4%) are considerable.

In the perspective of the SEAM4US research project, the most meaningful data is the 40% of savings achievable through control, not depending on lighting technology. Of course, this number has to be modulated by the dynamic control policy that will be applied. It is highly depending on the strategies of the subway manager too. In any case, considering the percentages in Table 1, it results that installing a control system in the platform of PdG-L3 station (48%of the overall lighting consumption), and keeping constantly the minimum regulation levels, a saving up to 20% of the energy consumption for lighting of the total station can be achieved.

6 CONCLUSIONS

This paper investigates the potential savings related to the upgrading of lighting systems in subway stations. Two lighting upgrading strategies are considered: equipment retrofit and integration of automatic control. A simulation-based scenario analysis was performed, comparing lighting performance and energy savings.

The results show a great potential for energy saving in this subway station, related to lighting system: 22-60% through the equipment upgrading approach, about 40% through the control approach, 60-77% through a combined approach. This analysis guided the initial phases of the SEAM4US project: it was decided to upgrade a part of the lighting system in the platform to LED fixtures and install a DALI control system, to be used as pilot for the research project. The new equipment will be installed in next months. Nevertheless, the good results achieved also with Fluorescent T5 lamps can justify further investigations about both technologies, extending the analysis to other spaces of the subway station, such as halls, corridors and stairs.

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Energy Assessment and Monitoring of Energy-Efficient House

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ABSTRACT: At present almost 100 registered passive houses can be seen in the Czech Republic, which were designed with help of software tools to achieve maximum energy efficiency. The feedback from the utilization of these buildings is very important for further improvement of the design techniques of energy efficient buildings and the development of existing calculation methods and other design tools. Information obtained throughout the monitoring of these passive houses and their technical systems give us valuable hindsight. New design methods based on computer simulations requires a comparison of results to those coming from long-term observations of energy performance.

This paper deals with modelling of an energy-efficient house with a subsequent comparison to determine the extent to which the model reflects the actual energy consumption of the house. Two modelling tools were used. These are the simple and easily accessible software PHPP and the more sophisticated modular simulation software TRNSYS.

1 INTRODUCTION

Currently, the building industry is one of the biggest consumers of energy, therefore European institutions do put a lot of effort to reduce their energy consumptions. The directive 2010/31/EU adopted by the European Parliament and the Council of the EU on the 19th of May 2010 among other states, that by the end of 2020 all of the newly erected buildings within the EU are to be designed as buildings with almost zero energy consumption. Thus it handles about null or plus buildings, which can be thought of as buildings corresponding to passive ones in their structural solution, but do utilise more of the available renewable energy resources to meet the needs of the building and for export.

When designing these buildings various simulation and calculation software tools are used already in the early phases of design to maximize energy savings. Nevertheless, feedback from actual operation of such buildings and their technical equipment is crucial too. Those then can be used as guides for the refinement of currently used calculation models and instruments. Howbeit, newly developed design methods as parts of computer simulation tools are to be validated against the results of long term observations of already erected building objects.

Therefore, the beginnings of the paper do focus on the description of an existing passive house on which one of the long-term energy measurements began and are still in course. The following sections do deal with energy modelling, comparison and determination of the extent which reflects how precisely the results of simulations do actually meet the real energy consumption of the house. The simulations of energy requirements were carried out in a simple and accessible design tool, namely PHPP (Passive House Planning Package) and in a more complex and sophisticated simulation software called as TRNSYS (Transient System Simulation Tool).

2 ENERGY MEASUREMENTS

2.1 *Description of the monitored building object*

The measurements started on a detached family house located in the village of Rapotice in the Czech Republic. It handles about a family house which is inhabited since October 2010. The dwelling has no basement and is based on a foundation slab of thickness 250 mm on top of a 200 mm thick layer of XPS. The flat roof is assembled from pre-fabricated elements and is thermally insulated by 300 mm of thermal insulation from EPS. This is then covered up by a steel sheet cladding in a slope of 6 °. The load bearing external walls are made from aerated porous concrete blocks YTONG with a thickness of 200mm closed up by 300 mm of grey polystyrene.

An air conditioning unit takes care of the airs ventilation, especially since it is provided with a cross plate heat exchanger for heat recovery. Because there are some losses, the air achieves its final temperature with the help of infra panels positioned on the ceilings of the rooms. In the bathrooms ladder rail radiator are to be found. The fresh air is drawn into the HVAC unit directly from outside or throughout an earth heat exchanger, depending on the temperature of air outside. The earth heat exchanger consists of PE pipes with a nominal diameter of 250 mm in a length of 36 m and at a depth of 3 m. The air from the HVAC unit is distributed to the residential areas directly, while the kitchen and bathrooms are supplied by fresh with the means of gaps under the doors without threshold, these rooms are the ones from which the air is then discharged. Warm water is prepared in a 300 l electric water boiler. From this it can be stated that electricity is the main carrier of energy used to meet the operational needs of the house, therefore it would be possible to deduct the overall electricity consumption from the house's electrometer. The family house can be seen on figure 1 and 2, and its detailed description is to be viewed in table 1.

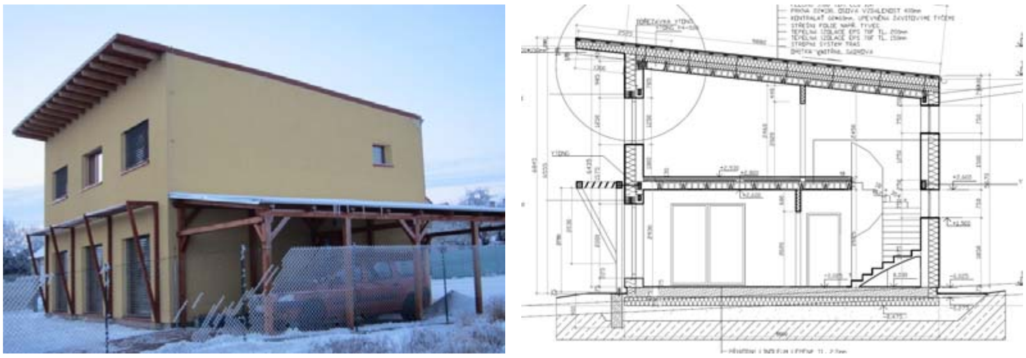

Figure 1. On the left – view of the building; on the right – a schematic section of the building.

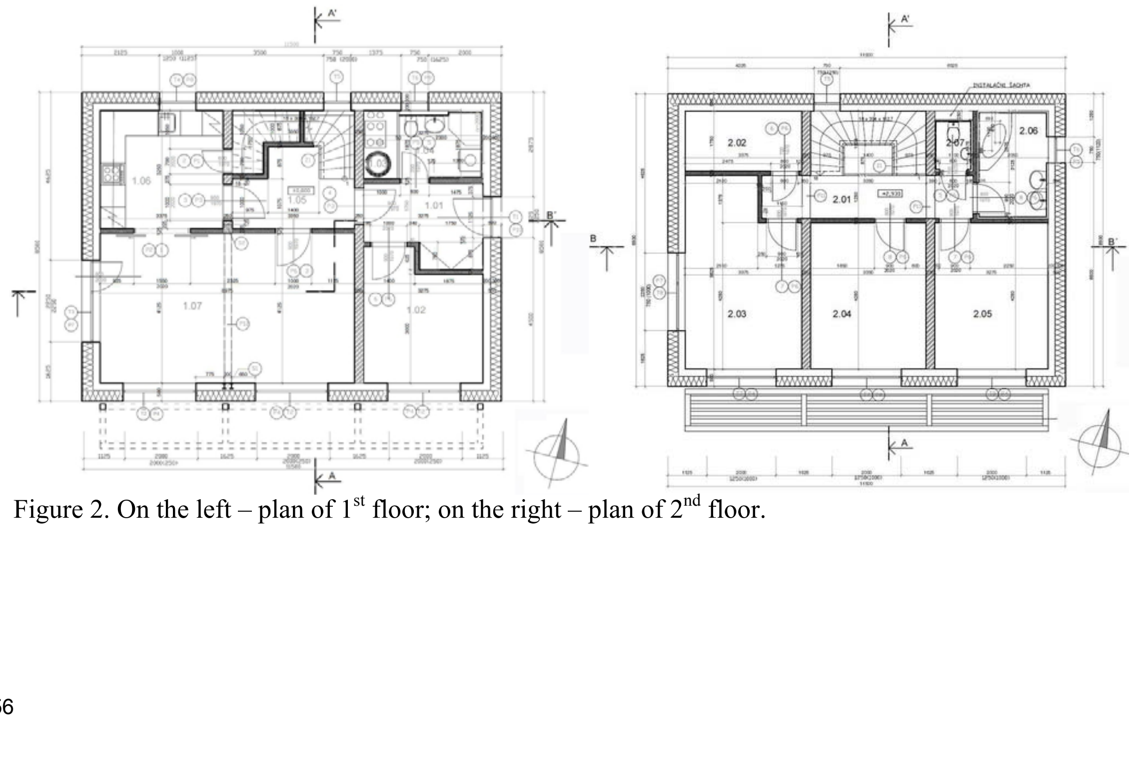

Figure 2. On the left – plan of 1st floor; on the right – plan of 2nd floor.

Table 1. Technical data of the building.

General data	
Location	Rapotice (Czech Republic) (49°11'13.788"N, 16°15'18.031"E)
Type of building	Detached family house
Number of floors	2
Number of flats	1
Number of inhabitants	2
Geometric data	
Built in volume (V)	635.4 m^3
Area of peripheral structures (A)	458.91 m^2
Ratio A/V	0.72
Area of floors	139.27 m^2
Thermal conductivity of the envelope	
External walls	U=0.097 W/(m^2.K)
Floors on the terrain	U=0.12 W/(m^2.K)
Roof	U=0.11 W/(m^2.K)
Fittings of openings (windows)	U_W=0.76-0.93 W/(m^2.K)
Characteristics of systems	
Heating	Infra panels Sun Waves SW 500W-K - power 500W
Air conditioning unit	Nilan Comfort 300 – efficiency of recuperation 88% (at 200m^3/h)
Earth heat exchanger	Length 36m, depth 3m, diameter DN250, PE, Rehau SN 100

2.2 *Measurements in the building object*

The aim of measurements is the monitoring and evaluation of energy flows, observation of the contribution of technical equipment and evaluation of energy consumption associated to the actual utilization of the house.

To measure the intensity of solar radiation a pyranometer was placed onto the roof. The parameters of temperature and humidity are recorded by two data loggers on the facade just below the overhang of the roof (one on the north and one on the south facade). Such data loggers were placed into the rooms too, to measure indoor micro climate.

Since the measurements are in the beginnings, the observation units are yet to be implemented into the earth heat exchanger. It handles about data based on the temperature of drawn in air by the HVAC unit. Furthermore, the power consumption meters are still to be installed onto all of the appliances and devices to determine their individual and total consumption of electricity and the specific heat consumption for heating

The house is connected to the electric network, only. Its total power consumption is known from bills from the previous years, since the object is occupied. In the first year due to the finishing touches requiring wet building processes the power consumption of heating was obviously higher, hence the values are not authoritative. Throughout the second year the house did utilise a total of 6.404 MWh of power, the value corresponds to the time interval from the 16th of September 2011 till the 20th of September 2012 (time difference between official readings).

3 ENERGY MODELLING

3.1 *PHPP (Passive House Planning Package)*

PHPP is a Europe wide recognized planning software. It is developed by Passive House Institute in Darmstadt and is widely used for the design of passive houses. It was first introduced in 1998. Since then it is continuously updated and developed. The software is based on the calculation methodology for the determination of energy balances of complex dynamic simulations, although it is relatively easy to operate because of simplifications, even while entering data. It works inside of a spreadsheet of MS Office Excel or OpenOffice.org Calc. The foundations of its usage do lie in sheets for the calculation of specific heat demand for heating, heat production and distribution, the need for electricity and primary energy demand. Gradually these were then complemented with newly added design modules (blades), such as the calculation of parameters of windows, shading and heat load and summer time. [Http://passiv.de/].

For the simulations represented within the paper PHPP of version 2007 was used. The procedure did include the same common steps as are used in practice while designing a building. This means that in the beginning the climatic data are selected from the included library for a certain location, that are closest to the point of interest. In this case it was the 30 km distant city of Brno. The whole building is considered as one zone and has a prevailing indoor temperature of 20 ° C.

The calculation neglects the internal structures, it is interested only in the envelope of the building, mainly those structures that are cooled down, including thermal bridges.

For each of the windows the average shading factor is evaluated, a shading induced by either the lining or by mainly screening with awnings and neighbouring buildings or both. It also considers temporary types of shielding such as blinds in the form of one value expresses in percentages. This special value must be estimated by the user himself.

While designing the system of forced ventilation the volume of exchanged air depends on the minimal value of ventilated air required by a person (25 m^3/(person.h)). The efficiencies of recuperation and earth heat exchanger are applied in the form of percentages. In case of the recuperation unit the values can be taken from the technical documentation supplied by the manufacturer. For the earth heat exchanger it must be determined with the help of available computer tools. For the simulations it described in the paper it handled about PHLuft, a software from the creators of PHPP. The efficiency of the earth heat exchanger did turn out to have a value of 21 %.

Furthermore, it is necessary to quantify the needs for electricity, which similarly to the determined heat demand is multiplied by the energy conversion factor, so it is possible to determine the specific requirements for primary energy.

3.2 *TRNSYS (TRaNsient SYstem Simulation Tool)*

TRNSYS is an advanced simulation tool, developed since the 70's of the 20th century by Madison University (USA). The software allows simulations to be done in the fields of solar thermal technology, alternative energy sources (including wind power, co-generation and fuel cells and related areas of heating) and last but not least ventilation and air-conditioning. It takes into account the geometry and properties of structures, glazed surfaces, latent heat storage of inner surfaces, internal heat gains, etc. The dynamic model in interaction with the defined profiles of zones and climatic conditions valid for the exterior balances the heat flow in all of the areas of a building in an hour based step. The definition of zones is individual (utilization, occupancy, lighting, heating and ventilation control, management solar gains). The result is a detailed and reliable calculation of heat demand, although it is time consuming to build the model of the building. TRNSYS requires a detailed knowledge of simulations of given physical issues as much as the software itself. [Matuska, 2012]

TRNSYS consists of two parts. The first is the solver that reads and processes the input files, repeatedly solves the entered model, defines the convergence and the system variables. The second part is the extensive library of modules (TYPE), each simulating a part of the system. Modules (TYPE) are designed in a way that a user can edit them if they already exist, or just define new ones. TRNSYS allows the modules and elements to be freely combined with a very wide choice of parameters. Due to the possibility of unlimited linking of individual modules (TYPE) in TRNSYS Studio it is relatively hard to maintain a simple and clear scheme (figure 3.).

The program allows one to save the output of any of the available modules as part of the results. It also allows the output to be displayed on the screen while making calculations to check the results during a simulation. The calculations are time consuming in case of large systems (it depends on the chosen time step).

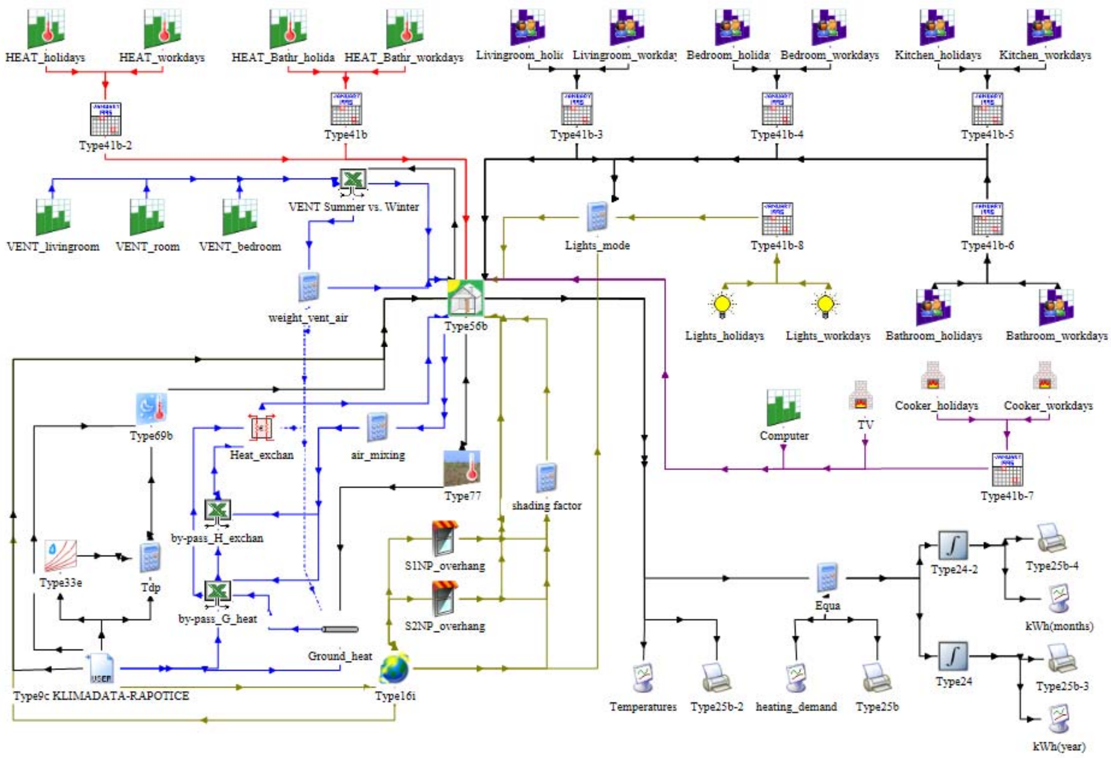

Figure 3. Simulation scheme of a project in TRNSYS Simulation Studio.

Table 2. TRNSYS types used and description of their role.

Type	Description	Role
56	Multi-zone Building	Modelling of multizone buildings in TRNBuild
9	Text Data Reader	Reading of local climatic data set
16	Radiation Processor	Determination of solar radiation on top of surfaces with varying orientation
34	Overhang and Wing wall Shading	Determination of diffuse radiation incoming to shaded windows
Equation	General	Determination of shading factor of sun-blind
33	Psychometrics	Defines T_{amb} and RH for type 56
Equation	General	Determination of dew point temperature
69	Sky Temperature	Defines T_{sky} for type 56
77	Ground Temperature	Models the temperature fields of soils
31	Pipe_Duct	Simulates the earth heat exchanger
62	Excel	Calls a pre-defined by-pass of the earth heat exchanger in Excel
91	Heat Exchanger	Models heat recuperation from exhaust air
62	Excel	Calls a pre-defined by-pass of recuperation in Excel
Equation	General	Determination of temperature of mixed exhaust air
14h	Forcing Functions-General	Defines ventilation modes
62	Excel	Decides the switching between winter and summer ventilation modes
Equation	General	Determination of overall volume and weight of exhaust air
14e	Forcing Functions-Temperature	Defines heating modes
41b	Forcing Function Sequencers	Defines working days, weekends and business holidays
14a	Forcing Functions-Occupancy	Defines the presence of people in the zone for heat gains
14d	Forcing Functions-Lighting	Defines luminaries in the zone for heat gains
Equation	General	Defines the conditions necessary to light
14h	Forcing Functions-General	Defines the operation of computers for heat gains
14c	Forcing Functions-Internal Gains	Specifies the heat gains coming from TV and stove
Equation	General	Converts the value to the desired units
24	Integrator	Summarizes the individual variables in the annual calculations
65	Online Plotter	Displays the plots of observed variables on screen
25	Printer	Save the monitored variables into a file

The most important part of the model is TYPE 56 – Multi-zone Building which allows the building to be divided up into several zones in the environment of TRNBuild (see figure 4.). Each of the set up zones can have windows including shading equipments and other structures. The shading was defined by the variable shading factor on the basis of the intensity of direct solar radiation incident to the window (see figure 4.), as is commonly kept by the tenant.

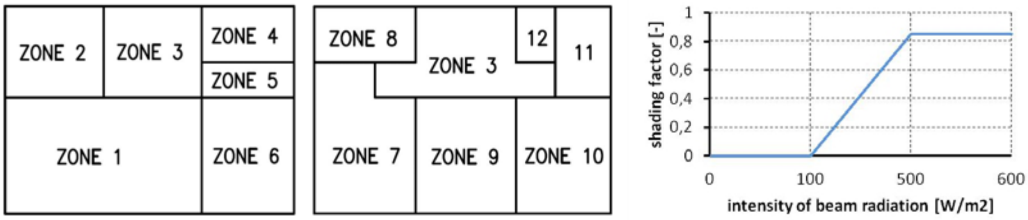

Figure 4. On the left – zones defined in TRNSYS for 1st floor, in the middle – zones defined in TRNSYS for the 2nd floor, on the right – dependence of shading factor on the incoming solar radiation.

If the intensity of direct solar radiation incident on the window exceeds 100 W/m^2, then the shading is initiated and reaches its maxima of 0.85 at 500 W/m^2 of radiation, since there is a need for natural light to penetrate the building at every time, hence the main aim is to save energy and because of the daylight there would be no need to turn on the luminaries.

Furthermore heating, ventilation and lighting modes are connected to the Multi-zone Buildings, though these are defined in separate types. The modes do vary depending on the definition of working and non-working days, also they may change during the day on the basis of utilization of the building. Lighting mode is once again set in conjunction to diffuse solar radiation incoming to the interior, and it is subjected to the presence of persons in the zone.

For internal heat gains the presence of users and the operation of major appliances the TYPES are defined distinctively.

The settings of climatic conditions and data does belong to the group of most important input parameters. For the dynamic simulations to be precise it is necessary to apply this kind of data for the locality, directly. The simulations described in the paper were carried out for data applicable for Rapotice, albeit it was created in accordance to EN ISO 15927-4 from the set of Reference climatic year valid for the Czech Republic. The climatic data also affects the varying temperature field of the soil, thus the efficiency of the earth heat exchanger. It had come to setting up a by-pass defining the conditions under which the air is drawn into the HVAC unit through the earth heat exchanger or just an opening in the facade. Then again another by-pass was implemented into the air conditioning unit. The by-pass chooses between recuperation and ventilation. The volume of exhaust air depends on the temperature of air in the interior.

4 RESULTS

In PHPP the main monitored values are clearly listed in the output form (Figure 5.). The output form includes specific heat demand required for heating, a value calculated by a non-normative procedure implemented into PHPP, with its value equal to 15.5 kWh / (m^2.a). Then the air-tightness of the building envelope, a token of passive houses. The air-tightness can not be obtained by calculation, only by the so called Blower Door test. The value of air-tightness has an informative purpose only in the output form. The last monitored entity is the specific amount of primary energy demand with a value of 104 kWh / (m^2.a), nonetheless for the comparison another variable is needed, that is the total demand for electricity, which is not featured in the output form, but can be easily found in another worksheet of the tool. It has a value of 38.7 kWh / (m^2.a).

TRNSYS as a dynamic simulation software fundamentally is not oriented to be used for energy rating of buildings, it has a much wider range of application in all of the industries. Because of this the results are not listed in an arranged sort of form, but the user can choose what entities are to be displayed, such as air temperature in each of the zones, heat losses of the zones, air temperature of air at the output of the earth heat exchanger, etc. The whole dynamic calculation process was set up at a hourly step throughout the year (8 760 hours) and thus it is evident how the building behaves at any time. The emphasis was primarily put onto the calculation of specific heat demand for heating. The calculated value for a years worth is 2 491 kWh (Figure 12th). At a floor area of 139.27 m^2 it gives 17.9 kWh / (m^2.a).

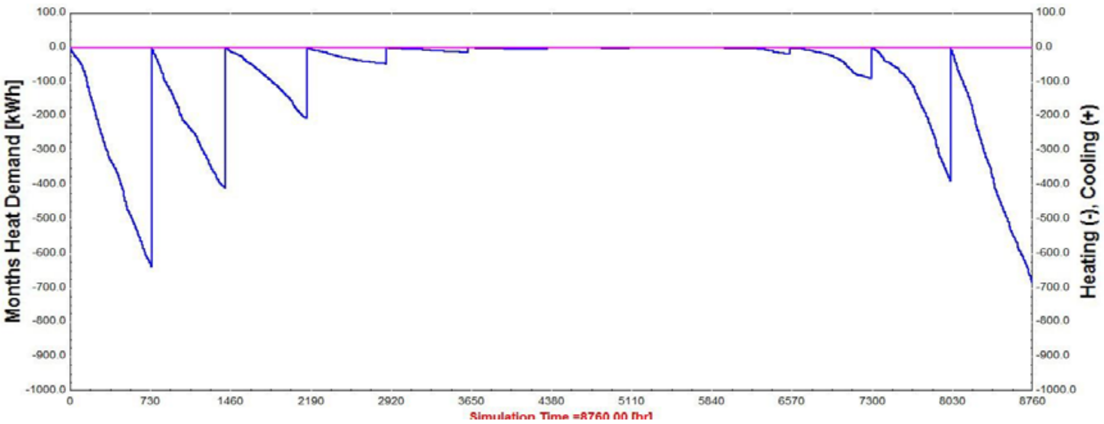

Figure 5. Monthly division of specific heat for heating via TRNSYS.

In the following table (Table 3.) the calculated monthly demand of specific heat is listed from both simulations

Table 3. Monthly specific heat consumption obtained by calculations in kWh/(m^2.a).

Program	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
PHPP	4.9	2.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	5.1	15.5
TRNSYS	4.6	2.9	1.5	0.3	0.1	0.0	0.0	0.0	0.1	0.6	2.8	4.9	17.9

5 DISCUSSION

When comparing the results (see figure 6.) from both available software for the monthly specific heat demand it can be seen that except for the extremes at the ends of the year (January and December) the values given by TRNSYS are higher than the ones coming from PHPP, even when the monthly values from PHPP are equal to zero. This is probably due to the fact that in PHPP the whole building object is input as one zone only with an internal temperature of 20 ° C, on the contrary in TRNSYS the house is divided up into several zones, such as for example the bathroom with an indoor temperature of 24 ° C. It makes simulations more challenging.

Figure 7. Comparison of monthly specific heat demand obtained by calculations in PHPP and TRNSYS.

From the aforementioned total estimated consumption of electricity in PHPP (8,7 kWh/(m^2.a)), about 40% did go to heating. At the exact same time according to TRNSYS the buildings total consumption of electricity is 44.75 kWh / (m2.a), which for a floor area of 139.27 m^2 gives 5.390 MW.h in the first case and 6.232 MW.h in the second. The real annual consumption of the building is 6.404 MW.h (Table 4.).

Table 4. Specific consumptions of electricity obtained throughout the evaluation process.

	Consumption of electricity [kWh/m^2.a]	Total consumption of electricity [MW.h]
PHPP	38,7	5,390
TRNSYS	44,75	6,232
Reality	45,98	6,404

To verify these facts it would be necessary to determine the true energy consumption for heating via long-term measurements.

In cases when the values are already known, the experience and professionalism of the user are the key element. Sometimes only small changes in setting of certain parameters can lead to desired results, but these changes can also compromise the objectivity of the assessment

6 CONCLUSION

It could be seen, that the results of dynamic simulations done in TRNSYS are quite accurate. The difference with respect to the actual values is relatively small. On the other hand the simplified procedure used in PHPP seems to have a higher errata. The difference in the calculated specific heat requirements for heating between the two programs reaches 2.4 kWh / (m2.a). In case of conventional building objects such a difference could be neglected, nevertheless for a passive house it is already a significant value. So, it was confirmed, that accurate results can be achieved only by simulations done on complex models. In the engineering practice however in most of the cases only simplified models and procedures are used because they are faster.

7 ACKNOWLEDGEMENT

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Chapter 5

Innovative Construction Systems

ECODOR: sustainable proportion for concrete sleeper

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ABSTRACT: Brazil is a large country and the railway in this context plays a key role enabling the transport of large volumes and also passengers, especially considering the rise of its domestic and foreign markets. This research is a study of technical and economic feasibility of a mixture used in manufacturing concrete sleepers, observing the environmental, social and economic problems that integrate the concept of sustainable development. In this context, a mixture of Portland cement, sand (from the waste of the marble processing), coarse aggregate (from the stamping gneisses) glass fiber (fiber optics waste) and water was used, measured in compressive strength, tensile strength by diametrical compression, modulus of elasticity and water absorption by immersion and capillarity tests, according to the standards generally prevailing. Finally, the results obtained present excellent mechanical and durability characteristics, being indicated the production of concrete sleepers named ECODOR (Ecological Sleeper).

1 INTRODUCTION

The Brazil Government intends to invest U$ 200 billion in the construction and reconstruction of more 10,000 km of railways along the 25 following years. That program aims to give continuity to the strategy adopted by the Growth Acceleration Program for railways with the participation of several companies for transporting loads.

The Brazilian railway system totals, now, 28465 km and its administration concentrated in the South, Southeast and Northeast areas (25% of the country's transportation of load) that will project for 2025, 35% of that transportation is made by means of trains.

The railway development depends on twelve factors presented in the Strategic Calendar for the Rail Transport of Loads Section where sustainable environment, sustainable technology (essential item for the railway development where it is intend to obtain new materials and technology in research and development institutions) and others are included.

For economical and environmental reasons, most of the recent studies went back to solutions to railway sleepers is concentrated in materials alternative to the wood, but transportation cost costs compared with the wood have to be considered (because they usually have greater weight).

Within the factors that guide a railway superstructure, it is necessary to design products for specific problems, for instance, the concrete railway sleeper rigidity, the recycling of materials, lower environmental impacts, and others.

The sustainable development in the 21 st century implies the reusability of products. There usually are economic and environmental incentives for recycling. In the case of concrete production, from an economic point of view, quality aggregate are in short supply in many places where concrete technology is needed, making it necessary to import quality aggregates from distant locations, and that is included the transportation costs. From the environmental point, the world consumption of concrete is approximately 5.0 billion tons a year.

Currently, the environmental regulations and urban development are already forcing the construction industry to seek alternatives to minimize transportation and disposal costs. Thus, many research the recycling of construction materials for concrete production. As a result of these economic and environmental benefits, the concept of recycling and reuse has gained momentum in the last decades.

Nowadays there is a lot of research on the use of the concrete production waste where the new composite have good physical and mechanical properties of the concrete. These researches analyze the technical viability of the alternative materials in a concrete mixture (Portland cement + artificial sand (crushed marble waste) + coarse aggregate (from the stamping gneisses) + glass fiber (optical fiber waste) and water/cement factor for production of the railway sleepers where the environmental impacts have to be considered, maintaining the durability. Finally, it was concluded that the proposed mix for concrete production, the sleepers production present excellent mechanical and durability characteristics and include the concepts about sustainable development (environmental, economic and social).

2 EXPERIMENTAL INVESTIGATION

2.1 *Item of Investigation*

In order to obtain concrete mixture for sleepers production with high quality used Portland cement, sand (fine aggregate - from the waste of the marble processing), coarse aggregate (from the stamping gneisses) glass fiber (optical fiber waste) and water in the proportion 1: 1.83 : 2.83 : 0.46 (Portland cement: artificial sand: coarse aggregate: water/cement ratio) and with or without addition of fiber optics waste 0.7%; the slump was 80 mm. This mixture was obtained in several previous development studies. Table 1 summarizes the test and has used the concrete cylinders in laboratory experiments.

Table 1 – Summary of tests performed and number of specimens tests (CPs)

	Age (days)	S Ts #	Test specimen (dimension)
Compressive Strength; Tensile Strength by Diametral Compression	3	6	10 x 20 cm
	7	6	10 x 20 cm
	28	6	10 x 20 cm
Modulus of Elasticity; Poisson’s coefficient	28	4	15 x 30 cm
Absorption of Water by Immersion, Capillary Absorption	28	4	10 x 20 cm
Flexion strength	28	4	15x15x60 cm

2.2 *Materials*

Cement: CP V Type Cement was used (see Table 2).
Aggregate: A fine aggregate resulting from the “crushing” of marble reject was used. In this research the glanulometric composition of the aggregate was developed in order to characterize it as optimum. Table 3 shows the characterization of the aggregate (AA – artificial aggregate (sand) and the coarse aggregate).
Addition: fiber optics waste of the production process of silicate and phosphate fiberglass with different diameters, covered with plastic resin (polyester), commercially named fiber optics for data transmission, added to the concrete for structural reinforcement.

Table 2 – Characteristics of CP V

Chemistry	(%)	Physical properties		Compressive strength	
SiO_2	19.21	Setting time (first) (min.)	125	days	fc (MPa)
Al_2O_3	4.98	Setting time (the end) (min.)	165	1	30.0
Fe_2O_3	2.95	Fineness modulus #325 (%)	2.8	3	40.8
CaO	64.0	volumetric expansion (mm)	0.0	7	45.5
MgO	0.73	Specific Density (cm^2/g)	4619	28	52.3
K_2O	0.81	PF (1000°C)	2.70		
CO_2	1.14	RI (%)	0.38		
SO_3	0.0				

Table 3 – Aggregate characteristics.

Properties	Artificial aggregate (sand)	Coarse aggregate
Maximum Diameter	4.80 mm	25.0 mm
Fineness Modulus	2.78	6.53
Specific Density	2.91 kg/dm³	2.70 kg/dm³
Bulk density	1.74 kg/dm³	1.36 kg/dm³
Powdered Material Content	5.00%	0.20 %
Organic Impurity	<300 p.p.m.	<300 p.p.m.
Water Absorption	1.27	0.0

3 EXPERIMENTAL RESULTS AND DISCUSSION

Table 4 presents the values found for each type in the tests for concrete with and without fiber waste, including the sample variation coefficients (CV), as can be seen they are less than 25%, proving the acceptability of the results.

Table 4 – Results of the experimental program with and without fiber waste (medium)
(cement: artificial sand: coarse aggregate: water/cement ratio: fiber reject/cement ratio – slump = 80 mm)
(1: 1.83 : 2.83 : 0.46 : (0,007)).

	Age (days)	with 0.7% fiber waste	CV (%)	without fiber waste	CV (%)
Compressive Strength (MPa)	3	26.16	1,54	19.65	8.83
	7	36.98	2,20	24.47	1.74
	28	46.30	3,50	35.49	1.37
Tensile Strength by Diametral Compression (MPa)	3	3.40	8,07	2.43	7.78
	7	4.97	3,02	3.51	2.91
	28	5.19	0,88	4.25	2.45
Flexion strength (MPa)	28	6.15	2,53	5.05	1.62
Modulus of Elasticity (GPa)	28	40.93	4,41	50.47	2.18
Poisson coefficient	28	0.38	6,74	0.47	8.92
Immersion Absorption of Water	28	5.47	2,01	5.55	1.36
Capillary Absorption	28	0.81	7,71	0.88	9.63

Analyzing the results, it is verified:

i) Compressive strength increased approximately 30% with the addition of fiber optics waste;
ii) Flexural strength increased approximately 20% with the addition of fiber optics waste;
iii) Elasticity Modulus and Poisson coefficient decreased approximately 20% with the addition of fiber optics waste;
iv) Absorption of water decreased approximately 10% with the addition of fiber optics waste.

Fibers have been used for a long time to reinforce brittle materials. The primary contribution of the addition of fibers is evident only after cracking the matrix. The fiber reinforced concrete has at least an order of magnitude of higher toughness (ductility, impact and others). Although most of the applications of fiber reinforced concrete rely on this increased toughness rather than on increased strength. Research in applying fracture mechanics concepts to quantify toughness and experimentally evaluate impact strength is continuing.

Adding fiber in concrete had a significant effect on the total energy absorption, and at the same time, more fiber content in concrete decreased the growth rate of total energy absorption because, in this research fiber addition was 0.7%.

The use of different types of fibers in varying shapes and sizes along with the ingredients of concrete was investigated to produce a composite material. The progress and economics of constructions technology depends on the intelligent use of materials and the continuous improvement of available materials.

There are many practices which can be used and, admittedly, many of which have already been implemented in an attempt to ensure sustainability. In the construction industry the following fundamental principles of sustainable development were suggested:

1) The use of industrial wastes (rejects) as raw materials for products;
2) The recycling of materials and products;
3) The development products which require minimal amounts of energy in the process of their manufacturing;
4) The use of renewable raw materials;
5) The development of products durable in a particular environment, for which they are designed.
6) Others.

Examples of different waste and recycled products used raw materials in concrete manufacturing were also provided. Developing countries have been identified as endowed with innovative materials with promise of partial or total substitution and the economic viability while ensuring the desired products and quality parameters.

The results obtained in this study suggest that the proportion of concrete with Portland cement, sand (from the reject of the marble processing), coarse aggregate (from the stamping gneisses), glass fiber (optical fiber reject) and water/cement present excellent mechanical and durability characteristics, being indicated in the production of concrete sleepers because they fulfill the sustainable development in the environmental, economic and social aspects, then named ECODOR (Ecological Sleeper).

4 CONCLUSIONS

As a pre-requisite for long term sustainability, it can be used in concrete to achieve one or several of the following: replacement of non-renewable materials with recycled materials or waste; reduction in energy requirements in concrete manufacturing; improvement of concrete durability in a particular environment; reduction of cost of materials; utilization of local unconventional raw materials (for example marble waste) in very low cost concrete.

Sustainability is important to the well-being of our planet, continued growth, and human development. Sustainable concrete should have a very low inherent energy requirement, be produced with waste, durable products and have a small impact on the environment. The “green” materials, which have high durability, high properties, low maintenance requirements and contain a large proportion of recycled or recyclable materials are important for the planet.

According to the World Commission on Environment and Development sustainability means “Meeting the needs of the present without compromising the ability of the future generations to meet their own needs. The sustainability of concrete products is imperative to the well-being of our planet and the human development, and the ECODOR includes the concept of sustainability (environmental, social and economic).

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Technical solutions and industrialised construction systems for advanced sustainable buildings

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ABSTRACT: At a time of severe market shrinkage, the spread of an approach to planning that is socially, economically and technologically sustainable, represents a culture of quality that is once more measurable, which makes it possible today to define innovative building models for the industrial and production chain.

The production of open industrialised building represents the most effective response to the need to recognise a reduction in building costs and times on site to ensure the environmental and economic sustainability of the intervention.

The concentration of effort and investment in processes and technologies aimed at a more rational energy use and exploitation of renewable energy sources (clean energy technologies) could act as a driving force for economic recovery by ensuring, at the same time, full agreement with energy and environmental constraints and international certification standards.

CCCabita - is an environment conscious constructive system that allows a coherent response, and a flexible one, to housing demand thanks to the potential for aggregating the residential blocks that define the different sizes of accommodation ensuring the adoption of the most innovative technical solutions and favouring the wider variability of the different housing models.

1 GENERAL INSTRUCTIONS

Today'sopen building systemsexpressthe best resultof innovation andexperimentationapplied to the fieldof building production. These systemsrepresentthe result ofa research pathtowardsbuilding technologies of rapid executionand highquality of the productwith whichto meet the needs of new forms of living, respond to economic demandsdictatedby the recessionin the construction sectorand introducetechnical elements that are attentive toprotecting the environment.

A more elaborate definition for industrialised construction means a change of thinking and practices to improve the production of construction to produce a high quality, customised built environment, through an integrated process, optimisingstandardisation, organisation, cost, value, mechanisation and automation.

Currently, there is a wide definition of Industrialised Building System that could be either the product or process: it is not necessarily restricting its scope to the final product which is a system but mainly involves the processes which lead to the production of the system and its construction application.

The International Council for Research and Innovation in Building and Construction (CIB) linked industrialisation with the use of mechanical power and tools, the use of a computerised steering system and tools, production in a continuous process, continuous improvement of efficiency, standardisation of products, prefabrication, rationalisation, modularisation and mass production.

From the perspective of construction, industrialisation is a part of a wider modernisation process through the development of modern methods of production and technology systems.

Many industrialised construction technologies coexist with onsite work in hybrid construction and so demarcating what constitutes offsite practice is problematic.

The Industrialised Construction Systems should be seen as an innovation in construction. The innovation agenda has been promoted worldwide as an evolution of construction using new and innovative techniques rather than a revolution.

2 INDUSTRIALISED CONSTRUCTION SYSTEMS

2.1 *Modern methods of production and technology systems*

The design and executive model of anopen constructive system is based on an“open building system” within whichthe various components andthe manytechnologies available on themarket(fromvertical closures to small elements, to closures in plates or panelsof dry-mounted wood, by industrialisedbaffles andprecastreinforced concrete pillars, to thedry or wet internal partitions) are inserted into amatrix of reference thatis the instrument formodular coordination, and verificationof tolerance and compatibility betweendifferenttechnologies and components.

However, industrialisation means an industrial method employed with reference to mechanisation, standardisation and prefabrication. In the lack of a uniform definition and uncertainty regarding the context and boundaries of the Industrialised Building System many different terms are used to describe industrialised construction and prefabrication. The term is used interchangeably with other terms like offsite construction, prefabrication, offsite manufacturing, Modern Method of Construction, industrialised building and industrialised construction.

Present-day manufacturing processesadhere to current building cultureas outlined and, in the form ofnew organicand systemic proposals, are reflectedin aproduction of catalogue systems: in these it is possible to detect the integration ofdifferent technological solutionsanddeterminetheir ability to meet, for each occasion, different project needs.

As partof the present-day logic at work in the construction market, the CCCabitaprojectrepresentsan innovativeopenindustrialisedbuilding system, which was born from the experiences andsynergiesofa plurality of subjectsgroupedina consortium,and havinga dual purpose: on the one hand, thedevelopment andtesting of modelsofsustainable social, private-public and student housingand, on the other,the promotionof the system with public and private clients.

The CCCabita project, promoted by the CCCabita Consortium, was awarded theEcosustainability andTechnological Innovation prize at theSocial Housing ExhibitionAwardsat EIRE(Expo ItalyReal Estate) 2010.

The CCCabita projecthas also been selected for an international competition forthe formationof the list of projects forhigh-performance and low-costresidential buildings at Housingcontest 2011.The competition,sponsored by the Cityof Milan in collaborationwiththe Association of Architectsof the Province ofMilan andotherassociations from the sector, involves anintervention on social residential housing of approximately5,000sqm ofGFAorganisedon five levels, following a typological and dimensional mix requested by the design for a total of66 dwellings. The projectillustrates the elevated characteristics ofaggregativeflexibilityof the living units,adapting themselves to the urban contextdefinedby the design integratinghousing typesandcompositional schemesof great importance.

2.2 *CCCabita - environment conscious constructive system*

The CCCabitaConsortium is formed from the integrationof a set ofcooperative businesses,in their capacity as partner manufacturers/producers, and a number ofprivate partiesthat constitute thepartners in the consortium.

Among the private partiesaresome of theleading companiesin the domestic marketrepresentingthe leading manufacturers/suppliersofindustrialised system components;thedifferentsuppliersflank boththe teamof operators specialisedin the fieldsof system engineeringandfinancial planning, as well as the academics and researchersdirectly involvedin the designof the system.

Through thisstrategicorganisationof the consortium,the various clients are always flanked throughout the entireprocess of implementationby expert consultants who-in relation to the different final uses,intervention programmes and specificprogrammatic needs-cansuggest andmodel on a case-by-case basis execution time,performances, production andmanagement costs oftheir projects.

The CCCabitasystem does nottherefore representa single projectbut, by virtue of the high levelof industrialisation of thesystem - and organisationof the consortium-allows the realisation ofa plurality ofconstruction interventions: the intervention can then becalibratedby adopting thespecificsolutionsin the catalogueprovided withinthe wide range oftechnical solutions belonging to the construction system.

Partners andtechnical choices form the basis of the constructive simplicityof the system; thequality ofmaterialsandproduct certification are a guarantee ofenvironmental sensitivityand of aparticular attentionto the life cycleof the buildingand its related operating andmanagement costs.

The high performanceof the materials usedin the technical solutionsofthe system arethe result of acertified and aware production cycle in which saving energy andreducing the environmental impactmeet the“quality credits” of the environmentalcertification protocolLEED® from which the CCCabitasystem takes its inspiration.

The approachof the working groupwastherefore toadoptas a priorityan operating instrument, of scientific validity, on the basis of which to evaluate the criteria of energyandenvironmentalsustainabilityof the buildings even before knowing theirfuturegeographical locationandenvironmental conditions.

2.3 *The technical manual for the CCCabita system*

The technical offerof the systemis structuredin atechnical-regulatory and typological manual, a tool that expressesthe wide architectural variability and technical specificationsof the system.The manualis divided into three different sections: the technical legislationof reference of a number of municipal realities, typological legislationand a catalogue of technological knowledge ofallofthe technical componentsof the system.

Thesystem manual offers itself thereforeas a tool forthe definition of the keyquality criteriaof the system and, intypologicalterms, for a complete compliance with national regulations.

Thesection on technical legislation brings together all thedesign standardsand housingparameters encodedby the variouslawsand that form thebasison which wasdeveloped the technical variability andflexibilityof the system.

Each alternativetechnique of the building systemreflectsand meetsthe entirebody of legislationat presentin force with regardto the following aspects: urban andtypological planning,structuralandantiseismic, plant, energyandfire safety.

Starting from the samplestudyof five cities(Rome, Florence, Bologna, Milan, Turin) standards have been definedof typological anddimensional architectural design, suggesting an approach to design that is flexible and easilyapplied throughout the entirenational territory and,in part, internationally as well. Building regulations, technical regulations for the implementationof town plans, and regional lawsareintegrated and translated intoa singleproject languagethat finds itsvalidityin the system’s legal manual: a toolat the disposalof clients and plannersfor the definition ofcubaturesand surface areasachievable on the basis of the building potentialavailable.

Thesection on typological legislation illustrates the means of aggregation of the dwellings that make up the individual living compartments,defininga mixedsettlement that is flexibleand compatible with the programmatic demands. The differentcombinations among the individual types ofaccommodationcanhave an effecton themorphology of the building all the way up to achieving theright mix ofhousing requested, as well as allowingmorearticulated building plant systems.

This objective of typological and morphological flexibilityhas been achievedby seekinga profound modularity and systematic nature in the structures and plant up to thedefinition of“services module” and the “technical plate”; the latter is the basis onwhich is built both the flexibility of the housing unitsand plant network, and the modularityof the façades.

Thetypological plant is definedby the aggregation ofelementsgeneratedby the threemodular units-A,B, C-that make upthe technical plate and which representthegeometric and spatialmatrixon whichis builtthe entire aggregativemodel of the settlement: theunits composeandaggregateto formdistinctconfigurationseach time. Theresidential blocks confer, through their composition andaggregation, an extensivecompositional freedom on thetypological plant; they representthe synthesisof the search formodularity and flexibilityof the system,disconnected and at the same timeconsistent with every technical, structural and plant choice.

Theopen systemis not limited tothe presentationof a singledistribution solution, butexpressesits potentialin the combined compatibilityof the multiplehousing units: different sizes of accommodationappropriately verifiedin theirtechnicaland optimisationfeasibility by thepartners involved in the consortium.

Thetypological developmentof the system represents the outcome of aplanning process thathas involvedandintegrated thedifferentpartnersthrough a continuoussharing of the different technical informationfromeach member of theteam; these activitieshave been followed by successivemoments ofverificationand control of the stagesof progress:a path ofprogressive approachto eachsolution-definitivelyvalidated - that represents theexpression of the best design synthesisbetween the ideational/composition process andthe know-how of the operatorsinvolvedin the executive development of the system.

Thespecificrules of technical compositionand verificationare provided in the typological manual of the system, anditexplains eachdistinctaggregative solutionclassified according tothe main typologicalrules of line, balcony/railingand gallery.

Thetypological-distributive plant is therefore basedon research into different consolidated settlement patterns responding,throughseparateresidential blocks, to the expectations ofa diversemultiplicityof users, and following thelogicsin placein the demographic andcompositional structureof the family groups (young couples, large families, studentaccommodation, students, single people, self-sufficientpeople with disabilities, the elderly).

The depthof the structure providesan early indicatorof the qualityand organisationof the system ofroutes anduse of space. The choice of aslenderbuilding emphasisesthe efficiency of thehousing modelto guarantee double exposureandcross-ventilation, which is also supported by mechanical ventilationthatoperateson both extraction of used air as well as on indoor thermal balance and comfort.

The section iscompletedby a matrixsummarising thesignificantmetric dataof the typologiesexamined and referring to the parametersexplainedin thetechnical regulations.

The catalogue of the technological system providesa morein-depth reading of the technologicalandconstructive aspects. The technical catalogue integratesand collects all thetechnical and plantalternatives of the systemand represents theanalytical foundationforthe construction of thetechnological matrixof the system.

The technicalmatrixsets out thepotentialrelationships between the differenttechnical solutions,whilethe constructive details solvethe maincritical pointsof the building (wall-coverings, wall-frames, wall-floor, overhangs, ground attachments) thatare verifiedin their performance response from both an acoustic andthermal-hygrometric point of view.

The detailed study of eachseparatesystem matrixobtainedfrom the integrationof the individualtechnicalsolutionsis presented througha firstoverviewthat, according to the hierarchicalarticulationof thetechnological systemin the appendixto the UNI8290:1981 norm, represents its synthesisand defines its representationshownin the scheduleof technical solutions.

Inthe schedule are described theindividualtechnical solutions andperformancesoffered by eachtechnical element. Each of theidentified solutionsis characterisedby the technicaland dimensional details of thematerials and productsadopted,expressing, in effect, the potential of theproject.

In this way all the solutions arecomparableto each otherwithoutany technical choice determining a technical discrimination against any others.

The technical catalogueof thebuilding systemis a valuable toolthat allows the recognition of thetechnological-performance efficacy of each alternativetechniquebut it is throughthe study ofthe connectionsand building nodes thatthe final qualityof the system is ensured.

The readingof the catalogueof thetechnological systemis completedby the development of exemplificative schemesand constructive details deriving from the applicationofvarious technical solutionsto each of thetypes of housingdeveloped.

These schemes showsome of the solutionsthatcan be pursuedthrough the CCCabita systemto which are linked a number of planning suggestions referring to pilot projectsthataccompanythe manual:the projects presentedillustratethe architectural possibilities that are the resultof the process ofintegration between planning choices under the typological-technological profile, of the sustainability and environmental compatibilityof the accommodation itself.

Each of thepilot projectsin the manualis accompanied bya financial project, a detailed analysisof the construction costs; a framework ofeconomic comparisonillustratesthe sameproject carried out withtraditional building techniques anditscomparison with thedifferent systemic solutionsproposed.The analysesalso highlight the calculation ofgross leasable areaandparameter values -defined by theprice per surface - referring to the different configurations of the technological system.

The economic analysisis accompanied by aschedule of activitiesthat illustrates the conveniencesand peculiaritiesof the different systemsover a period of time from the planningto theimplementation phases during building.

3 INNOVATIVE AND TECHNICAL SOLUTIONS FOR OPEN INDUSTRIALISED BUILDING

3.1 *Integration of technical solutions in the CCCabita construction system*

The constructive integration promoted by the CCCabita Consortium is defined by the implementation of the housing model with construction systems that are innovative or derived from the hybridisation of these solutions with more traditional elements, combined in new sectors of industrial production.

The matrices of compatibility between the different technical solutions in the catalogue define the integration of a number of technological systems, each of which is assigned a specific identity number: the structural solutions, diversified by morphology, material and procedure for mounting/assembly on site, are the main factor for the determination of each system.

A first industrialised system is defined by a monolithic structure with supporting partitions in lightly reinforced cement conglomerate, built through insulated formworks in polystyrene (producer Nidyon-Consorzio Etruria); this solution is highly successful insofar as it allows the realisation of any typological configuration and helps to eliminate any thermal bridges for the benefit of the thermal-hygrometric performance of the building. The solution can be used for both closures and internal partitions.

A second system, with greater internal flexibility in the dwelling, is based on a precise structural system with multilevel pillars, precast beams in reinforced concrete and prestressed hollow core floors (producer APE). The hyperstatic system allows a considerable reduction in the time to completion and limits the presence of structural elements within the spans, favouring in this way a greater flexibility and aggregability of the separate living units.

This solution does not interfere with the closing solutions nor with the internal partitions which in this way can be realised with different solutions: external dry-mounted closures in OSB framed panels (producer Holzbau), or pre-assembled LCS modules (producer Diwem); dry-mounted internal partitions of variable thickness covered with plasterboard and gypsum fibre (thickness 125 mm, sound reduction index Rw=58 dB, thickness 215 mm, sound reduction index Rw=66 dB) (producer Saint Gobain); external walls made of masonry in vibrocompressed cement conglomerate with low environmental impact, with pre-and post-consumer recycled content of more than 40% (thickness 30 cm, sound reduction index > 57 dB) coated or multilayer (producer Vibrapac); interior walls in elements in vibrocompressed cement conglomerate of variable thickness if internal partitions in the dwelling (12 cm thick, sound reduction index > 45 dB) or partitions between different units (thickness 15 cm, sound reduction index > 47 dB).

A third system involves the construction of closures, floors and structural elements through multilayer bearing panels in totally dry-mounted cross-lam wood. The frame of the structure is made up of large linear elements that contribute to the elimination of thermal bridges, a considerable reduction of the thickness of the building envelope, and can cover an entire wall with a single element up to a maximum length equal to 20 m.

The walls and floors - both internal and covering - can be easily connected with standardised connecting elements offering both lightness and speed of assembly.

The constructive nodes are solved and developed in a definitive way in the design phase, reducing the risk of error during the engineering and implementation phase.

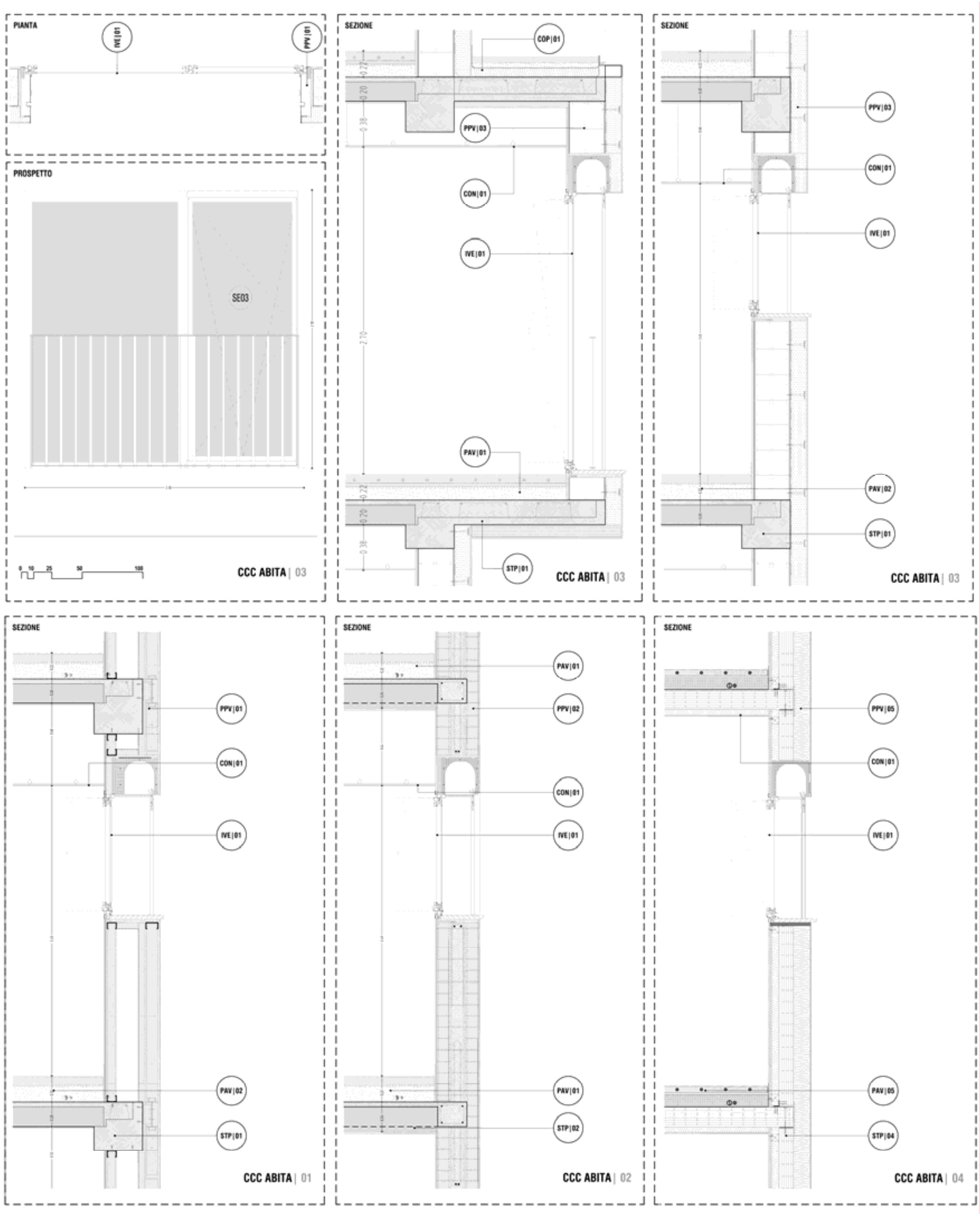

Figure 5. Flexibility of the technological offer.

The modularity of the opaque elements used goes with that of the three modules of glass closures; these last are made with high-performance energy frames and involve the most innovative systems of transparent enclosures. The exterior doors are made of thermal aluminium alloy profiles (producer Schuco) and insulating double glazing that can guarantee values of thermal transmittance (Uglass) of 1.1 W/sqm k, solar factor (SF) of 55% and noise reduction Rw of 42 dB. The windows are fitted with a prefabricated box for the housing of roller blinds made of a one-piece high density (35 kg/mc) self-extinguishing expanded sintered polystyrene.

The attention to the aspects of an energy and thermo-hygrometric wellbeing nature within the environmental units is also reflected in the technical choices for the partition, such as the heated flooring in the interior and ceilings that ensure the achievement of LEED® credits thanks to the high percentage of recycled material contained and because it is easily renewable.

The plasterboard false ceilings (producer Saint Gobain), essential for the use of industrialised floors, provide for reduced thickness, respond effectively to the plant integrability and improve the acoustic quality of the building. In correspondence to the balconies and open spaces the false ceilings combat, through the insertion of insulation, the thermal differences with the outside.

3.2 *Plant equipment*

Since this is a modular design the plant equipment mentioned below refers to the plant plan for a building of 66 lodgings which involves the generation of hot and cold fluids and hot water from a central location. The generation system consists of a cycle-inversion heat pump with desuperheater is capable of recovering up to 25% of the waste heat of the process. The energy obtained from the re-use of waste heat released by the machine integrates with the energy supplied by the thermal vacuum solar panels placed on the roof for the production of domestic hot water (DHW). This is stored in a thermal puffer of 6,000 liters, which allows for use even in bad weather conditions or in cases of high and simultaneous request by the users.

The photovoltaic system - which is also on the roof - provides 275 monocrystalline modules (producer Saint Gobain) for a total power of 66 kW peak to guarantee 1kW peak per dwelling.

The residences are also equipped with a system of centralised control and supervision for the recording of the consumption of electric power, heating/refrigeration for temperature control of the environments, and hot and cold water.

Heating/cooling inside the housing is of the radiant type supplied with fluid at 40/35 °C in winter and 18/21 °C in summer. The radiant panels are made with the “knuckles” system or the anchoring of polyethylene pipes of specially shaped plastic panel inside dry or wet screed. Below this panel there is provision for the insertion of a layer of insulate shaped in relation to the surrounding environment, as foreseen by the norm UNI EN 1264. The attachments for heating/cooling circuits in correspondence of the collector are provided with electrothermal actuators that allow the opening and closing of the circuit in relation to the incoming signal from the thermostats in the building, obtaining in this way a modulated ambient temperature. In each main room in fact there is a digital thermostat through which the user can adjust the temperature set-point.

Humidity control is ensured by a system of mechanical ventilation controlled with an integrated compressor which is much more efficient than traditional crossover flow recovery: the air drawn from outside, before being introduced into the environment is preheated (pre-cooled) thanks to the energy recovered from the expelled air through an active thermodynamic process in a circuit with a reversible heat pump. Thanks to this heat recovery from the expelled air, the ventilation system can autonomously satisfy the heat demand of a dwelling up to 5 °C of the ambient external air temperature. The air changes guaranteed, in agreement with UNI 10339:1995, are equal to 30 mc/ h/person.

The adjustment of the air conditioning is both environmental and climatic insofar as produced by means of thermostats within the dwellings and an external sensor connected to the thermal power plant.

The lighting of external lights (gardens and coverage) is controlled by programmable control switches; the lights in the stairwells are equipped with actuators controlled by infrared presence detectors favouring in this way a considerable saving in terms of energy consumption.

4 CONCLUSIONS

Industrial production has been practiced on a large scale since the Second World War but now industrialisation enables the construction industry to manage material and energy flows better. It not only creates new opportunities, it also forces the construction industry to adapt new practices, following open and closed prefab systems.

The new practices include: reduce, reuse and recycle resources; eliminate toxic substances from construction; apply life cycle economics in decision making; create a quality built environment.

Industrialized construction - offsite standardized manufacturing of building parts and even of whole buildings - has shown to contribute to the achievement of at least a large part of the objectives for the construction of advanced sustainable buildings.

Open industrialisation regards not only residential buildings, but is reached by all building sectors by making agreements about methodology, measurement systematics and connections.

In a design approach, technical principles, based on a dynamic open building systems and products, are developed, in order to separate the different building layers and to deconstruct building components.

Those projects are evaluated by users and other stakeholders. If necessary the generative design approach will be improved, the technical principles could be revised and dynamic solutions can be implemented in the system.

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A project contribution to the development of sustainable multi-storey timber buildings

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ABSTRACT: Wood is a natural material, renewable, easily recyclable, and able to store carbon-dioxide, which makes tall timber buildings a solution with potential to answer the main sustainability targets. Cross laminated timber (CLT) has been pointed out as the best wood-based material to make this ambition a real thing. In order to understand why, this paper introduces the material and describe some demonstration buildings recently built.
Based on diagnosed weaknesses of CLT buildings, it is presented an initial propose for a new CLT/glulam hybrid construction system, called Urban Timber (UT) system, which aims be able to support taller timber buildings. The main motivation was the development of a wood-based structural solution that provides more spatial flexibility and wider versatility for visual architectural expressions. The system is described and illustrated, considering concerns related with structural behavior, architectural value, structural connections and wood shrinkage.

1 TALL TIMBER BUILDINGS IN THE CITY

1.1 *A brief introduction*

The continuous increase of the urban density all around the world forced cities to grow taller, making tall buildings an ordinary typology in developed cities. The urban population keeps growing, foreseeing that until 2050 the world population living in cities will reach 70% (Green & Eric Karsh 2012), which indicates that tall buildings will become even more common. Unfortunately, tall buildings are generally linked to great negative impacts on environment, raising the need to look for new environment friendly solutions. Tall timber buildings are a concept that emerged connected with this need, betting on wood sustainable profile as the key factor to reduce the negative environmental impact of construction sector. In some countries where timber has a social character, such as Sweden, German and Japan, timber is positively appreciated as a building material (Stehn & Bergström 2002). However, this subject can face serious barriers in countries where wood culture doesn’t exist. Regardless of these difficulties, tall timber buildings are an exciting and current topic, expecting that their qualitative advantages overcome remaining socio-cultural barriers.

Cross laminated timber (CLT) is an engineered timber product that has been largely associated to the concepts of tall timber buildings due to its enhanced mechanical properties, mass and technological facilities. CLT constructions are often cited as a great sustainable solution due to their capacity for store a large amount of carbon dioxide (Green & Eric Karsh 2012, Omland & Tonning 2009).

1.2 *Sustainability targets – Social, Environmental, and Financial*

Regarding to sustainability concerns, CLT tall timber buildings has been proofing their viability in all three main sustainability targets, namely: environmental sustainability, financial sustainability and social sustainability (see Fig. 1). Sustainable profile linked to timber as a construction material can be a strong ally to recent European environmental policies, namely EU's 20/20/20 plan. Indeed, timber is a natural material, renewable, recyclable and able to store carbon dioxide. This last feature is the most important one once each timber building works like a carbon dioxide reservoir, which will only be emitted into the atmosphere upon combustion or decay of timber. Some numbers related with carbon storage of CLT buildings has been recently published. According to respective designers, Stadhaus, in London, saved 310 tonnes of carbon (Kucharek 2009) and Forté, in Australia, promoted an overall saving of 1451 tonnes of Carbon (Heaton 2013).

The financial sustainability of CLT is closely related with savings provided by technical facilities and rigorous project design. In one hand, material production is industrialized and based on a computerized numerical control (CNC), which ensures a high precision of elements demanded and reduces waste material. On the other hand, the simplicity of construction, associated to timber easy handling and prefabrication allows a significant reduction of construction time, to simplify the site apparatus and an increase of the on-site safety. As consequence of these advantages, promoters of Stadhaus and Forté experienced a fast construction time, 11 and 12 months, respectively, with a reduced site team and less and low-tech equipments (Silva et al. 2012). This reduction represents approximately a saving of 30% on construction time when compared to a concrete system (Patterson 2013). However, based on numbers pointed by economical analysis, CLT is still 5% more expensive than a similar solution in concrete. This fact is related essentially with the large amount of timber used and with the use of gypsum boards to fulfill fire safety performance (Winter et al. 2012).

Finally, social sustainability is related with mental and wellbeing of people, a dimension where quantitative and qualitative aspects should be carefully balanced. In other words, a dimension where architecture should be pragmatic, answering issues like daylight, economy and energy consumption, as well as abstract answering issues related with architectural expression and spatial organization and orientation. As regards to functional and safety requirements, there are research initiatives that have assessed the safety of a CLT tall building in several areas, such as: fire safety (Dagenais et al. 2013, Frangi et al. 2008), durability (McClung 2013, Patterson 2013), sound insulation (Hu & Adams 2013) and thermal performance (Glass et al. 2013).

The design versatility is a chacteristic of CLT construction system however, when applied to tall buildings, the common systems exhibit some spatial limitations related with great number of structural partition walls, as well as limitations related with opening dimensions. For that, the present paper is essentially focused on exploiting a new way to overcome these limitations.

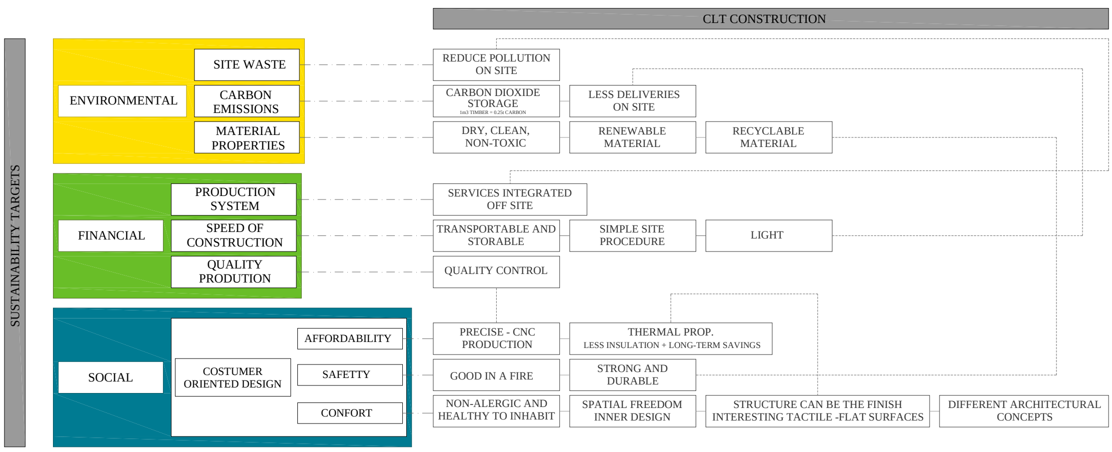


Figure 1. Sketch about correlation between sustainability targets and CLT construction.

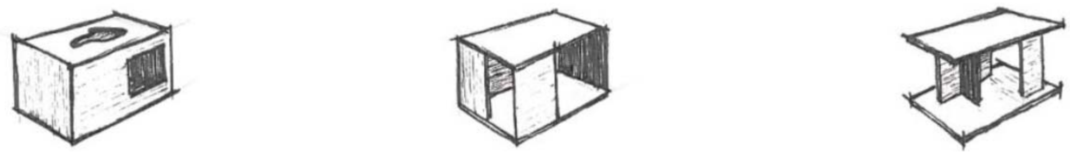
2 CLT AS A BUILDING MATERIAL

2.1 *The plate*

CLT is a prefabricated solid engineered wood product composed of switched orthogonally bonded layers of solid-sawn timber or structural composite lumber. As final result CLT exhibits a panel shape, different from well known linear timber elements. Besides, cross layers provides to CLT panels higher strength and stiffness properties in their both directions, being able to take up forces in-plane as well as perpendicular to the plane. Thus, CLT panels may work as a shear wall as well as a slab (Bejder 2012).

CLT elements introduce timber in the field of surface-based expression, known in society since 1970’s when emerged prefabricated buildings in concrete (Falk 2005). But, better than concrete, CLT offers huge format, light weight and easier workability. The dimensions of panels can be adjusted according to project needs, however there are dimensional limits essentially related with transport. Panels can have from three up to seven layers, which means thicknesses between 42 and 500mm. Width and length of panels can go up to 4800 and 30,000 mm, respectively. But, due to transportation and assembling restrictions width and length of CLT panels are limited to 3000 and 16,500mm, respectively (Augustin 2008).

The adaptation of CLT to engineering and architecture practices has been described by some authors. Falk (2005) defined structural behavior of structures based on timber *plates*, explaining the significance of orientation of walls and shear-walls as well as warning for stability dependency on both orientation and jointing. Regards to architectural issues, Bejder (2012) defined different possibilities to construct with CLT. According to that work, there are three different ways to build with a *plate-based* system, which result in distinct final architectural expressions and spatial configurations (see Fig. 2).



(a) (b) (c)

Figure 2. Three different spatial configurations based on plate properties suggested by (Bejder 2012). (a) *Enclosed box*, (b) *dissolved box* and (c) *‘floating’ structure*.

2.2 *Limitations imposed by building scale*

Regarding buildings with a reduced number of floors, CLT is a very attractive material possessing a significant number of qualities. The massive and isotropic *plate* allows for great freedom during designing process, allowing different building overall shapes, different spatial configurations, and freedom on openings location, shapes and size. Further, force transferring properties of a plate structure allows floor-structures with wide spans (approximately 7.5m (Augustin 2008)), wall-structures working as deep beams, and columns can be used as supports without main beams (Falk 2005).

However, when CLT is the only structural material of a tall building, the design freedom suggested before is limited. Structurally, CLT has been mentioned as a good material to build tall with timber once it is a massive material with improved mechanical properties. Further, massive construction is characterized by its monolithic behavior, based on distribution of bearing walls able to provide to structure a higher level of strength and stiffness.

Nevertheless, tall building requires the adequate stiffness to answer horizontal forces derived from wind or hazards, which means the need of increase the mass of structure. Thus, CLT construction took refuge in a super massive system called *cellular construction*. It can be classified as a ‘selfish system’ grounded on the multi-functionality of CLT claiming that the entire building should be built up with CLT elements. In other words, it is a system in which CLT should shapes all structural elements.

Cellular construction has been recently applied in some recent tall buildings exposing some important limitations associated to this system. Beyond the stiffness requirements, this kind of system can promote progressive collapse requiring extra load paths through the increase in the number of structural walls. At the end, the building shows an enclosed external image with small openings and inner spaces, excessively compartmentalized. This last is the reason why typical CLT tall buildings have been essentially limited to residential buildings.

Aware of that obstacle, enthusiasts of tall timber construction have started to encourage engineers and architects to work on new solutions able to offer greater freedom to designers and meet actual customer needs. There are already some proposals to reduce the excessive partition space, such as: located reinforced cores and some hybrid structural systems that promise to boost the emergence of new ideas. New solutions should bet on exploration of material strength, local strengthening of bearing points and increase stiffness, in order to allow more daring and creative results (Wells 2011).

3 DEMONSTRATION CLT BUILDINGS AND THEIR CONSTRUCTION SYSTEMS

3.1 *Cellular construction*

In last few years some CLT tall buildings, with a range of storeys between 8 and 10, have been built in order to prove their viability and their advantages. The most known examples are Stadthaus and Bridport in London (UK) and Forté in Melbourne's Docklands (Australia). All buildings are based on *cellular construction*, in which CLT shapes walls and floors. Structural stability is provided by bearing walls and stairs/shift cores, built with thicker CLT elements or a double layer wall.

Despite the excessive number of partition walls present in these three buildings, it is possible to note some flexibility on location and orientation of bearing walls and cores. All three buildings present different overall shapes. Stadhaus presents a simple square implantation, Bridport bets in a less slender long shape, while Forté suggests something more irregular, broking the square monotony with protrusions and angles which also offer greater diversity of views to different apartments. However, all of them show an external expression of an enclosed box (Silva et al. 2012). This is a consequent result when a construction system is entirely based on CLT elements, which requires the location of vertical load paths in façade elements.

Regarding to functional requirements, like fire safety, thermal and acoustic behavior and durability, all studied buildings respected the building code requirements. In fact, nowadays the ability of CLT to answer these functional requirements is not an assumption anymore. As mentioned in point 1.2, several research projects have been studying the best construction measures to ensure that CLT buildings can offer safe and comfortable solutions. Usually, to respect fire and acoustic requirements the walls sections are covered with 1 or 2 layers of gypsum boards, creating an air gap where is located the acoustic insulation material. Thermal behavior is not a matter of concern once low heat conductivity of timber answers the requirements itself. At last, durability is guaranteed through the application of impermeable and breathable sheets on exterior face of CLT elements, protecting timber from water contact and significant changes in its moisture content.

3.2 *Proposed innovative solutions*

Challenging the limitations of CLT tall buildings, some innovative proposals, based on hybrid and lighter concepts, have been emerging. Barents house, project by Reiulf Ramstad Architects (Reid 2010), and FFTT system (find the forests through the trees), developed by Michael Green and Eric Karsh (Green & Eric Karsh 2012), are two of these proposals looking for solutions able to offer greater spatial amplitude, suitable to non-residential uses and reach higher heights.

Barents house is a project for a timber building with 20 storeys which bet in a structural system that combines CLT floors, glulam beams, columns and diagonals, and a concrete core. FFTT system is able to reach 30 storeys and bets on the combination of CLT walls and floors with steel beams. The reduction of timber amount, and consequent reduction of space partition, is possible due to the increase in the building stiffness warranted by concrete and steel elements (Silva et al. 2012).

4 UT SYSTEM

Urban Timber (UT) system is an initial proposal, similar to the hybrid solutions presented above, looking for a tall timber solution able to answer actual demands from society while respecting the principals of sustainability. *UT system* can be classified as a hybrid timber solution once it tries to propose an entirely timber-based system, avoiding the use of steel or concrete, but denying the selfish '*all with CLT*' concept. It combines two different timber engineered products, namely CLT and glulam, resulting in a lighter solution able to conceive more economical and challenging buildings.

4.1 *Structural system*

Structurally, *UT system* is inspired in the *bundled tube* concept, which works like a cluster of individual tubes connected together in such a way that they behave as a single unit. The advantage of such kind of concept is that the three-dimensional response of the structure result in an improvement of strength and stiffness provided by cross frames in the building (Ali & Moon 2007).

The proposed system is based in the combination of CLT and glulam, in which CLT shapes floors, walls and deep beams, while glulam shapes only beams. CLT walls have the function to resist gravity loads, either with a vertical load path or an oblique one, and resist lateral loads by means of shear walls. CLT floors work together with glulam beams distributing loads to CLT walls, improving the building stiffness and avoiding the effect of progressive collapse. Finally, CLT deep beams sew up all individual tubes in the building perimeter.

Tall buildings have greater vulnerability to lateral forces, especially wind loads, which means that the building perimeter has more structural significance. So, *UT system* suggests a structure in which major part of lateral load-resisting system is located on building perimeter, but as recommended for any exterior structural system, there are also some minor components within the interior of the building (Ali & Moon 2007). Further, considering the fact that shear-plates provide more stiffness than the corresponding elements in a frame construction (Falk 2005), the external lateral load-resisting system is performed by CLT shear walls positioned in building perimeter and oriented perpendicularly to facade plane.

Figures 3 and 4 exhibits a proposal for a building based on *UT system* principals in which both external and internal lateral resisting elements are arranged in two principal orthogonal directions. As shown in Figure 3, lateral load resisting system can be improved by means of great shear walls, located in building corners oriented in both main axis of structural system.

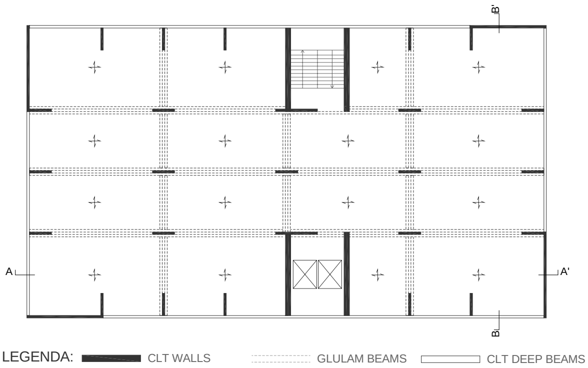


Figure 3. Structural plan proposal of *UT system*.

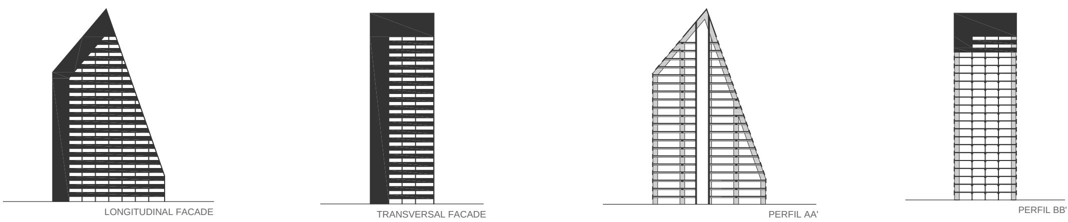


Figure 4. Facades and cross sections of a proposed building using *UT system* .

4.2 *Wood moisture content concerns*

Shrinkage considerations should always be considered during the design process of a tall timber building, even using timber engineering products subjected to a rigorous control of moisture levels (between 10 and 14% (Augustin 2008)).

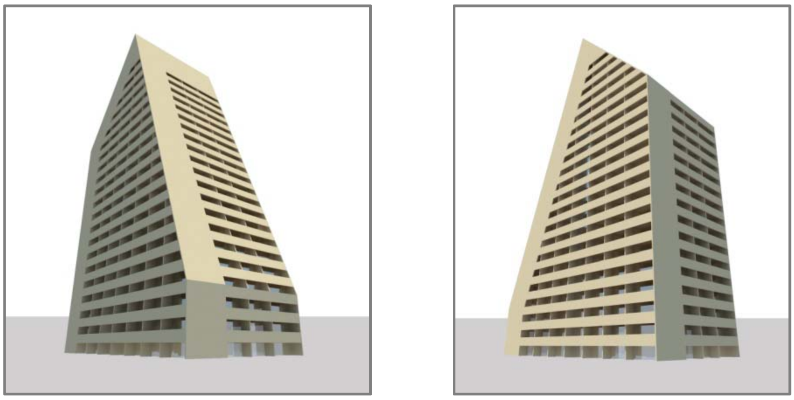
Based on cross lamination benefits, it is proclaimed that CLT is a dimensionally stable material along its main axis (Augustin 2008). However, as a precaution, *UT system* is based on balloom-frame construction, taking advantage of panel length to experience slightly less accumulative shrinkage over the height of the building. A more troubling issue is related with shrinkage across the thickness of CLT that is logically greater due to its solid timber composition. To overcome this matter, *UT system* presents the combination between CLT floors and glulam beams as a possible solution once in this way CLT floors don't rest directly in CLT walls. In this way, glulam beam ensures a continuous support to CLT floor which is not only dependent on steel connection between panels, reducing any influence that moisture variations could exert on connections behavior.

Another important issue concerning moisture is the exposition of CLT facade panels to two distinct environments (exterior and interior), which can cause some distortions on those structural elements (Lepage 2012, McClung 2013). In *UT system*, the placement of structural walls perpendicular to façade can reduce the significance of this subject when it consider the position of balconies in the entire perimeter of building. In this way, the contact of the structural elements that are part of façade system with the interior environment is limited.

4.3 *Architectural considerations – Architecture being pragmatic as well as abstract*

The main architectural focus of *UT system* is to maximize the freedom in the creative act that architecture represents. A powerful vocabulary for a variety of existing building forms it is proposed.

Beginning with building plan shape, in a bundled tube system, the individual tubes could be of different shapes, such as rectangular, triangular or hexagonal (Ali & Moon 2007). This plan diversity is also possible with *cellular construction* as proved by demonstration buildings described in point 3.1. However, in buildings supported entirely by CLT elements the irregularity of building shape only results from a simple extrusion of plan shape. So, as shown in Figure 5, the great innovative proposal of *UT system* is the possibility of a volumetric freedom, allowing angles between ground and façade planes.



(a) (b)

Figure 5. 3D model of a proposed building based on *UT system*.

Keeping the discussion on external view, the orientation of CLT walls perpendicular to façade allows wider openings, and CLT deep beams allows a strong sense of horizontality not possible with a typical *cellular construction*. Further, façade walls can perform a significant role on solar protection and can also be designed to create different façade effects. That's when the technology behind CLT production can be useful to architectural expression. The CNC technology associated to CLT production enables the production of panels with different shapes without prejudice to the production process. Despite prefabrication is often correlated with modular architecture, this don't means that it don't allow personalized solutions (Larsson et al. 2012).

Relatively to internal spaces, *UT system* don't offers an extreme open space concept, as proposed by Michael Green with FFTT system, however, it allows to place interior frame lines without seriously compromising interior space planning. Moreover, with a *bundled tube* concept it is possible to free vertical cores.

UT system is the result of a process that tries to dissolve the box suggested by *cellular construction*. As result, the perception of the plates as a bearing skeleton increases and the spatial enclosure is generated by a composition of separate elements. Considering the spatial configurations proposed by (Bejder 2012), *UT system* is located between the called *dissolved box* and the *'floating' structure*. Vertical elements do not define the interior space while CLT deep beams define the relation between interior and exterior.

4.4 *Joints*

Joints in timber play a significant role on behavior and capacity of the structure, namely on building stiffness and energy dissipation (Fragiacomo et al. 2011). Timber connections exist in a great variety due to timber workability, but they have to be adequately selected and designed depending on each situation.

CLT connections are usually based on simple and relatively low-tech principles, mainly based on self-tapping screws. Exploiting these advantages, *UT system* suggests connections based on self-tapping screws and steel rods.

The main connection in *UT system* includes CLT and glulam elements, in which glulam beams perform an intermediate role transferring loads from CLT floor to CLT walls. As CLT floor rests on the top of glulam beam, the connection between them is based in the simple insertion of self-tapping screws perpendicular to the grain axis. Differently, the connection between glulam and CLT walls is performed by steel rods which connect two glulam beams and a CLT wall located between them. Steel rods were preferred instead of self-tapping screws in order to ensure that the two glulam beams work together and, therefore, an improvement in the connection stiffness is obtained (see Fig. 6).

The connection of CLT walls and floors with CLT deep beams is performed by simple self tapping screws inserted diagonally to CLT planes (see Fig. 6). Screws are arranged under an angle of 45°, (or less when CLT deep beams are sloping) between screw axis and member axis in order to provide a higher load-carrying capacity compared to common shear connections due to the high withdrawal capacity of the self-tapping screws (Krenn & Schickhofer 2009). The use of steel plates is avoided once the connection can be located in elements exposed to external environments.

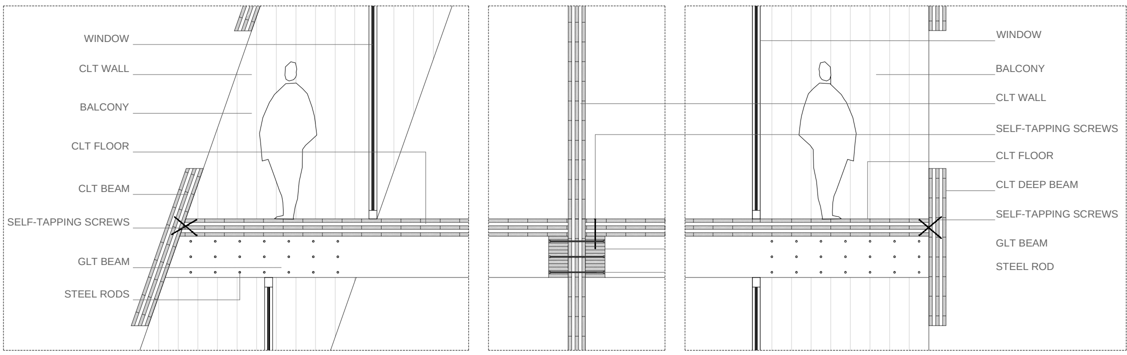


Figure 6. Details of *UT system* connections.

5 CONCLUSION

Obviously, the future of CLT in urban context should not be only based on tall buildings. However, this kind of buildings has been proofing potential to be a well spread typology in denser cities. Actually, tall CLT buildings have been mainly supported by qualitative reasons, such as sustainable advantages, but this typology can't develop properly only based on that. So, CLT systems must look for more economical solutions able to support taller buildings and more challenging architectural solutions.

UT system tries to make the CLT use more attractive to construction market looking for a solution able to answer adequately quantitative and qualitative the actual requests. The focus on a timber hybrid solution allows both, keeping the ecological advantages and reaching a higher level of versatility and freedom in the architectural design. This system is still in an initial phase of development being necessary to assess its real viability with further research steps, namely to study the design taking into account the structural and functional requirements of the existing building codes.

Finally, it must be said that the search for new CLT constructions systems should keep exploiting properly the multifunctional qualities of CLT plate-shape, generating new ways of thinking, designing and building with wood.

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ARGAD: High Performance Mortar

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ABSTRACT: The use of industrial wastes arouses great interest to the extent that they can contribute both to the reduction of costs and to sustainable development. In this context, an increase in the number of studies on alternative materials in civil construction can be seen. The difficulty in obtaining sands near urban centers, resulting in an increase in the final price of the aggregate due to transportation costs, must also be considered. The mining industries, mainly of ornamental stone, produce a high volume of waste, which pollutes and degrades the environment. This research has characterized and evaluated the use of crushed marble waste to replace natural sand for the production of mortar. in the following in Physical and mechanical properties of some types of mortars were researched. Finally, it was concluded that the mortars made with marble waste present excellent mechanical and durability characteristics, being named ARGAD (High Performance Mortars).

1 INTRODUCTION

The use of industrial waste arouses great interest because they can contribute to the reduction of costs of the deposit areas and to sustainable development, soon an increase is verified in the number of studies on alternative materials in civil construction. In the case of extraction of natural sand from riverbeds that result in damage for environmental, often irreversible. The difficulty in obtaining of sands near urban centers resulting in an increase in the high price of the aggregate when considering the transportation costs.

The extraction of ornamental rocks in Brazil is near to 5.2 million metric tons/year, with a volume of waste on the order of: 30% in the production of slabs and 25% in the process of commercialization, resulting in, approximately, 390,000 metric tons of waste/year. The waste from marble processing, still little exploited, has potential use in civil construction and there are several researches that demonstrated the possibility of using this waste as aggregate for the production of concrete and others.

This research evaluated the technological properties of full substitution of natural sand for marble waste (artificial sand (AA)) in the mortars. The compositions (Portland cement + hydrated lime + artificial sand + water/cement) were subjected to tests for strength to axial compression, tensile strength by diametral compression, modulus of elasticity; pull-off; shrinkage; absorption capacity. Based on the results found that the mortar produced with the marble waste, being named: ARGAD (High Performance Mortars).

2 EXPERIMENTAL INVESTIGATION

2.1 *Item of Investigation*

In order to obtain mortars with many applications (flooring, wall and ceiling coating), a proportioning of materials based on two consistencies was performed, namely: 180 mm (± 10 mm) and

210 mm (± 10 mm); adopted due to the desired workability in the construction site; maintaining a cohesive mixture, with no segregation. The workability and the water/cement were obtained with the aid of the flow table. The influence of the addition of hydrated lime, being a composition constituent, was also evaluated, therefore: cement, hydrated lime and artificial sand, the water/cement factor being determined as a function of workability, as illustrated in tables 1 and 2 (table 2 has the number of the test specimen). All the tests used the Brazilian standard.

Table 1 – Types used in the experimental program (cement : lime : artificial sand : water/cement)

Workability = 180 mm (± 10)	Workability = 210 mm (± 10)
1:0:3:0.58	1:0:3:0.72
1:1:2:1.11	1:1:2:1.33
1:0:7:1.12	1:0:7:1.32
1:1:6:1.40	1:1:6:1.72
1:0:10:1.53	1:0:10:1:95
1:1:9:1.50	1:1:9:1:2.10

Table 2 – Summary of tests performed and number of test specimens (CPs)

TEST	Age (days)	nº STs
Compressive Strength; Tensile Strength by Diametral Compression	3	4
	7	4
	28	4
Capillary Absorption of Water; Modulus of Elasticity; Pull-Off; Shrinkage	28	4

2.2 *Materials*

Cement: Type CP II-E-32 Cement was used (see Table 3)

Table 3 – Characteristics of CP II–E-32

Chemistry	(%)	Physical properties		Compressive strength	
SiO_2	24.05	Setting time (first) (min.)	190	days	fc (MPa)
Al_2O_3	7.15	Setting time (the end) (min.)	240	1	8.6
Fe_2O_3	2.47	Fineness modulus #325 (%)	17.1	3	24.8
CaO	57.50	volumetric expansion (mm)	0.0	7	32.3
MgO	3.36	Specific Density (cm^2/g)	4181	28	40.9
K_2O	0.60	PF (1000°C)	4.71		
CO_2	3.41	RI (%)	2.06		
SO_3	1.84				

Lime: Type CH I Hydrated Lime with Additives was used (see Table 4).

Table 4 – Characteristics of Hydrated lime (CHI)

Chemistry	($C0_2$)	≤ 5%
	CaO + MgO Hydrated	≤ 10%
Physical	fineness modulus #0.075 (%)	≤ 10%
	water retention	≤ 75%
	volumetric expansion	absent
	plasticity	≥ 110

Aggregate: A fine aggregate resulting from the “crushing” of marble waste was used. In this research the granulometric composition of the aggregate was developed in order to characterize it as optimum. Table 5 shows the characterization of the aggregate (AA), table 6 and 7 show chemistry and petrology analysis, respectively.

Table 6 and 7 indicated that the aggregate does not have sufficient mineral so as to cause an alkali-aggregate reaction (non-reactive), such as: opal, cristobalite, silica and others.

Table 5 – Physical characteristics of the AA.

Maximum Diameter	4.80 mm	Powdered Material Content	5.00%
Fineness Modulus	2.58	Organic Impurity	<300p.p.m.
Specific Density	2.91 kg/dm³	Water Absorption	1.27%

Table 6 – Chemistry analysis of the AA - Classification: Magnesium

Main component	%
Ca	18,1
Mg	12,9
CaO	25,4
MgO	7,8

Table 7 – Petrology analysis of the AA (*The sum of the three minerals is 2%)

Mineral	Chemistry formula	%
Carbonate	$(CaCO_3)$ or $(CaMg(CO_3)_2)$	95%
Olivine – Fosterite	(Mg_2SiO_4)	3%
Chlorite – Mg	$(Mg_{12}[(Si,Al)_8O_{20}](OH)_{16})$	*
Serpentine	$Mg_3[Si_2O_5](OH)_4$	*
Amphibole - Tremolite	$[Ca_2Mg_5Si_8O_{22}(OH_2)]$	*

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 *Compressive strength and tensile strength by diametral compression*

Tables 8 through 11 present the values found for each type in the tests of compressive strength and tensile strength by diametral compression, including the coefficients of variation of the sample (CV), as it can be seen they are less than 25%, proving the acceptability of the results.

Analyzing the results, it is verified that the 7-day old mortars made with AA have a mechanical strength (tension and compression) about 60% of the final strength; this result indicates high strength. This fact is attributed to the granulometry and the lower water absorption of the aggregate. The benefits of the hydrated lime are proven in plasticity and cohesion (fresh state).

Table 8 – Results of the Compressive Strength test (medium results), in MPa, workability of 180 mm.

	7 DAYS		14 DAYS		28 DAYS	
	f_c (MPa)	CV(%)	f_c (MPa)	CV(%)	f_c (MPa)	CV(%)
1:0:3:0.58	19.60	3.86	22.11	5.60	25.85	4.87
1:1:2:1.11	6.64	6.89	7.50	2.32	10.06	5.58
1:0:7:1.12	5.77	4.47	8.94	7.34	11.54	6.14
1:1:6:1.40	5.55	1.40	5.91	2.69	8.65	0.17
1:0:10:1.53	4.36	15.08	5.29	9.25	6.28	10.62
1:1:9:1.50	4.47	5.00	5.86	0.03	7.13	0.20

Table 9 – Results of the Compressive Strength test (medium results), in MPa, workability of 210 mm.

	7 DAYS		14 DAYS		28 DAYS	
	f_c (MPa)	CV (%)	f_c (MPa)	CV (%)	f_c (MPa)	CV(%)
1:0:3:0.72	16.64	1.56	16.90	2.07	23.19	8.79
1:1:2:1.33	4.76	10.66	6.17	1.65	7.65	1.55
1:0:7:1.32	5.17	0.35	7.27	16.70	10.16	7.92
1:1:6:1.72	3.30	4.59	4.00	0.49	4.88	19.26
1:0:10:1.95	3.05	1.44	3.18	0.56	4.92	9.61
1:1:9:2.10	2.72	1.30	2.91	3.63	4.11	12.93

Table 10 – Results of the Tensile Strength by Diametral Compression and workability equal to 180 mm.

	7 DAYS		14 DAYS		28 DAYS	
	$f_{ct,sp}$ (MPa)	CV (%)	$f_{ct,sp}$ (MPa)	CV (%)	$f_{ct,sp}$ (MPa)	CV (%)
01:00:03:0.58	2.55	13.15	2.75	0.17	4.28	7.67
01:01:02:1.11	0.97	4.30	1.17	11.64	1.46	7.27
01:00:07:1.12	1.20	0.67	1.41	4.11	1.91	7.04
01:01:06:1.40	0.69	7.20	0.86	1.77	1.23	7.13
01:00:10:1.53	0.50	9.17	0.57	7.13	0.95	2.32
01:01:09:1.50	0.73	10.95	0.75	4.18	0.87	8.57

Table 11 – Results of the Tensile Strength by Diametral Compression and workability equal to 210 mm.

	7 DAYS		14 DAYS		28 DAYS	
	$f_{ct,sp}$ (MPa)	CV (%)	$f_{ct,sp}$ (MPa)	CV (%)	$f_{ct,sp}$ (MPa)	CV (%)
01:00:03:0.72	1.84	5.40	2.48	11.26	3.09	10.71
01:01:02:1.33	0.81	4.42	1.12	4.80	1.53	13.62
01:00:07:1.32	0.98	4.80	1.33	1.87	1.78	1.06
01:01:06:1.72	0.62	3.19	0.85	3.39	1.15	5.09
01:00:10:1.95	0.72	1.25	0.90	1.82	1.26	4.00
01:01:09:2.10	0.47	8.22	0.73	0.60	0.94	11.81

These results on the mortar allows admitting them as being high strength when compared with normal mortar. Within this context, the designation of ARGAD was adopted. It is evident that higher strengths can be obtained with the reduction of the w/c factor.

The regression was done and the correlation between f_c with $f_{ct,sp}$ as illustrated in Figure 1 and Equation 1.

$$f_{ct,sp} = 0.1709 f_c + 0.3366 \quad (1)$$

Where: $f_{tc,sp}$ = Tensile Strength by Diametral Compression, in MPa;
f_c = Compressive Strength, in MPa.

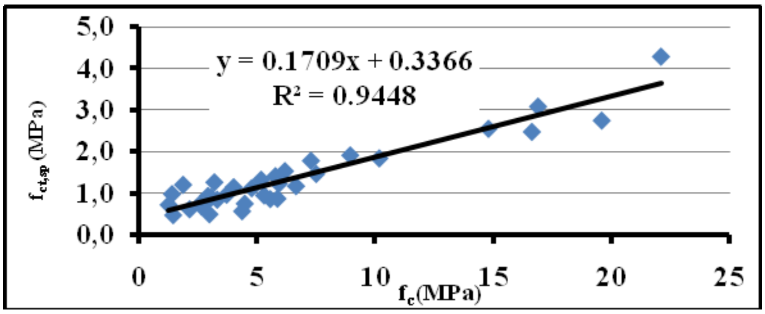

Figure 1 - Tensile Strength by Diametral Compression (MPa) x Compressive Strength (MPa).

3.2 *Modulus of Elasticity*

Tables 12 and 13 showing the results is strongly related with mechanical strength. The Static Modulus of Elasticity has high values for mortars without lime, showing its relationship with mechanical strength, due to greater compactness and resilience.

Analyzing Table 13, it appears that there is a correlation between E_{ci} and f_c and $f_{ct,sp}$, as shown in Equations 2 through 5.

For Workability of 180 mm:

$$Eci = 602.31\, fc + 295 \quad (2)$$

$$Eci = 3{,}058.23\, fct,sp + 425 \quad (3)$$

For Workability of 210 mm:

$$Eci = 730,65\ fc + 198 \quad (4)$$

$$Eci = 4,851.43\ fct,sp + 2761 \quad (5)$$

Where: E_{ci} = Static Modulus of Elasticity, in MPa
f_c = Compressive Strength, in MPa
$f_{ct,sp}$ = Tensile Strength by Diametral Compression, in MPa

Table 12 – Results of the static modulus of elasticity (E_{ci}) for mortars with AA.

	Workability = 180 mm		Workability = 210 mm	
	E_{ci} (GPa)	CV (%)	E_{ci} (GPa)	CV (%)
01:00:03	13.35	1.78	12.61	10.26
01:01:02	5.37	12.98	4.24	4.86
01:00:07	6.55	2.86	5.48	7.72
01:01:06	4.35	1.32	3.99	3.13
01:00:10	2.33	19.79	1.83	1.59
01:01:09	3.32	12.82	2.58	0.00

Table 13 – Comparison between E_{ci}, f_c and $f_{ct,sp}$.

	Workability = 180 mm			Workability = 210 mm		
	E_{ci} (GPa)	f_c (MPa)	$f_{ct,sp}$ (MPa)	E_{ci} (GPa)	f_c (MPa)	$f_{ct,sp}$(MPa)
01:00:03	13.35	25.85	4.28	12.61	23.19	3.09
01:01:02	5.37	10.06	1.46	4.24	7.65	1.53
01:00:07	6.55	14.06	1.91	5.48	14.90	1.78
01:01:06	4.35	9.45	1.23	3.99	6.57	1.15
01:00:10	2.33	6.28	0.95	1.83	4.92	1.26
01:01:09	3.32	7.13	0.87	2.58	4.11	0.94

Where: E_{ci} – Static Modulus of Elasticity; f_c– Compressive Strength; $F_{ct,sp}$ – Tensile Strength by Diametral Compression

3.3 *Pull off Tensile Strength*

Pull-off tensile strength (R_A), with the respective values of coefficient of variation (CV) and correlations between this property and compressive strength (f_c) and tensile strength by diametral compression ($f_{ct,sp}$), is presented in Table 14 and Figure 6.

Analyzing Table 14 and Figure 2, it can be seen that the Pull-Off Tensile Strength (R_A) is being inversely proportional to the addition of water. In the attempt to obtain correlations adequate to the results, a regression was done resulting in Equations 6 through 9.

It appears that the pull-off tensile strength is close to 11% to 13% of the compressive strength, close to that obtained for tensile strength by diametral compression. The classification of the mortars to pull-off tensile strength is high pull-off resistance.

Table 14 – Mean of the results of pull-off tensile strength (R_A).

	Workability = 180 mm		Workability = 210 mm	
	R_A (MPa)	CV(%)	R_A(MPa)	CV(%)
01:00:03	2.925	0.17	2.790	0.13
01:01:02	1.500	2.04	1.350	1.24
01:00:07	1.700	2.75	1.600	3.01
01:01:06	1.100	3.69	1.160	2.23
01:00:10	0.900	5.11	0.850	4.11
01:01:09	0.950	1.45	0.900	2.31

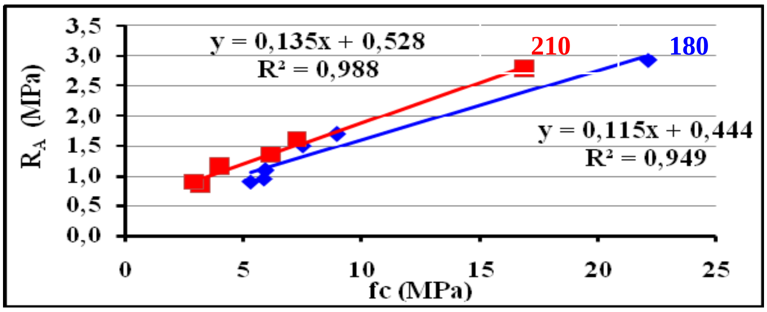

Figure 2 – Correlation between Pull-Off Tensile Strength (RA) (MPa) x f_c (MPa) when 28 days old.

For Workability of 180 mm:

$$R_A = 0.1355 f_c + 0.52 \quad (6)$$

$$RA = 1.662 fct,sp + 0.73 \quad (7)$$

For Workability of 210 mm:

$$RA = 0.1152 fc + 0.44 \quad (8)$$

$$RA = 1.0602 fct,sp + 0.09 \quad (9)$$

Where: R_A = Pull-Off Tensile Strength, in MPa
$f_{ct,sp}$ = Tensile Strength by Diametral Compression, in MPa
f_c = Compressive Strength, in MPa.

3.4 *Capillary Absorption*

In the case of capillary absorption of the mortars studied, a property associated with the conditions of durability, the results are found in Figures 3 and 4. On analyzing the Figures, it can be seen that the increase in the proportion of aggregate increases capillary absorption. The porosity depending on the lower proportion of cement, resulting in a more permeable cement matrix and allowing aggressive agents access to the interior of the mortar. According to SANTOS (2011) these results present no risks related to durability when exposed to the presence of water, provided that basic care is taken to protect them, such as, for example, painting.

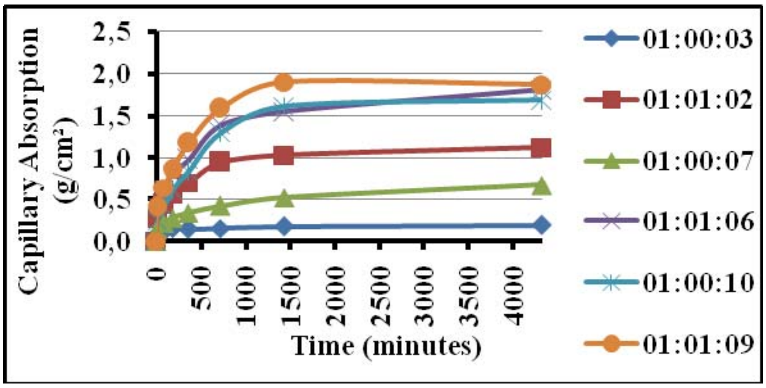

Figure 3 – Capillary water absorption x time of exposure for mortars and a workability of 180 mm.

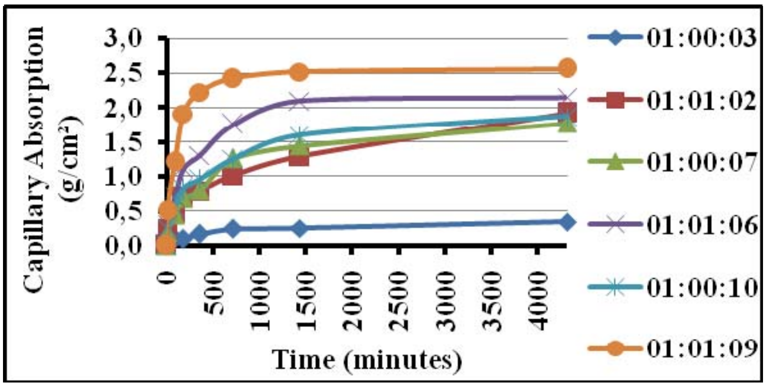

Figure 4 – Capillary water absorption x time of exposure for mortars and a workability of 210 mm.

3.5 *Hydraulic Retraction*

Hydraulic retraction may result in several conditions such as: mapped cracks, water flow to the interior of constructions via cracks, accumulation of microorganisms, among others; which does not compromise the durability of the building, in addition to giving visual effect. Figures 9 and 10 present the evolution of the retraction for the mortars analyzed.

Analyzing Figures 5 and 6, it is clear that the increase in the quantity of water increases the hydraulic retraction of the mortars with lime, a longer time for their stabilization being necessary. It can be seen, further, that the hydraulic retraction is less for the mortars without lime due to the non-existence of the fines of this agglomerate and to the hardening process.

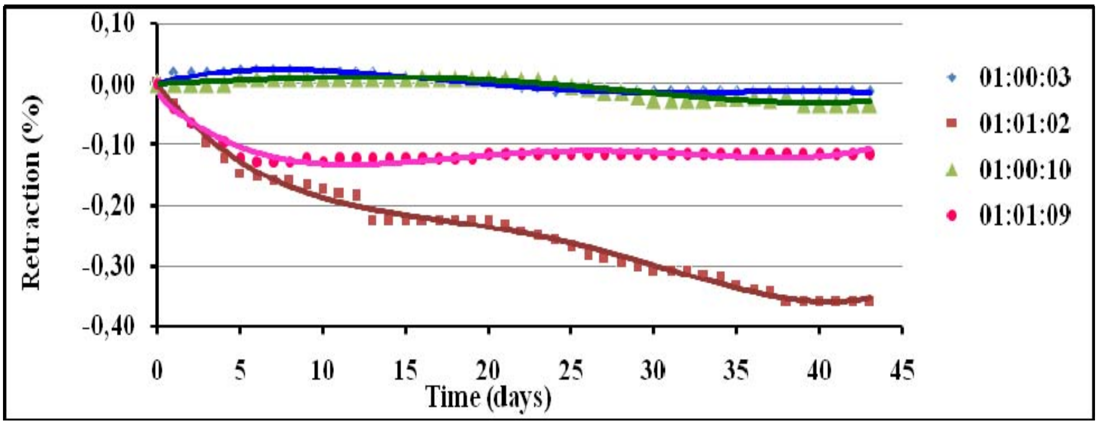

Figure 5 – Hydraulic Retraction x Time, workability of 180 mm

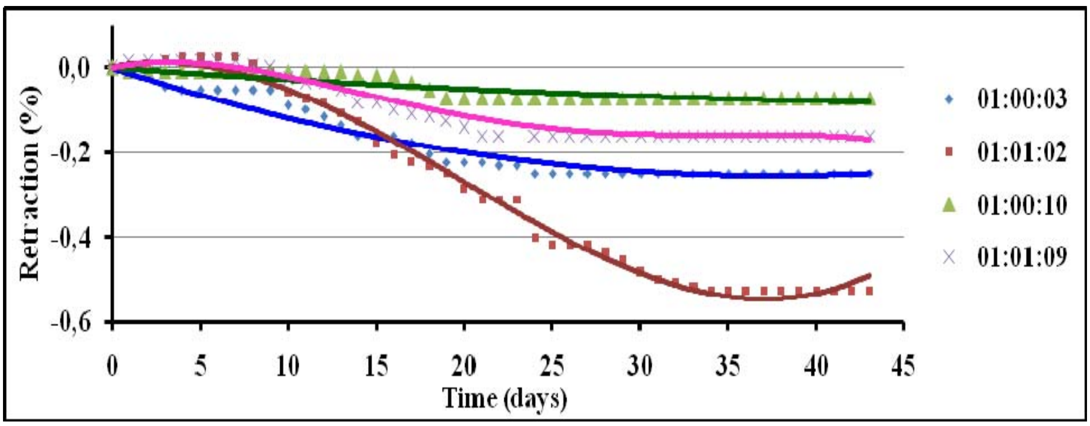

Figure 6 – Hydraulic Retraction x Time, workability of 210 mm

4 CONCLUSIONS

The topic of “Reuse of Waste” in Constructed Environment demonstrates its importance, not just in the design and production of buildings, but within the supply chains of the Civil Construction sector. It deals with the global trend to seek reuse rather than high exploitation.

The recycling of waste presents itself as an adequate methodology in the development of new products which have performances compatible with the technical standards and do no attack the environment. In the case of waste, the object of this research, it is clear that the results were compatible and superior, demonstrating great benefits acquired by this new product, in the confection of mortars.

Proving the superiority of mortars fabricated with artificial aggregate, from the crushing of marble waste, it was chosen to call this new material AGRAD: High Performance Mortar, analogous to concretes, by setting up a technological innovation, with improved characteristics when compared to other mortars, allowing more diversified uses, with less consumption of cement and reducing the price of the final product, making it more competitive in the market.

By what was shown, it is verified that this new product is based on sustainable development, i.e., on social, environmental, economic and institutional factors.

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Lightweight Steel Framed Construction System

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ABSTRACT: Lightweight steel framed (LSF) structural elements in buildings construction provide a way of raising building sustainability. These structural elements have several advantages, such as presenting a great potential for recycling and reuse, allowing the conservation of natural resources and the environment. The high thermal conductivity of steel could be a drawback, leading to thermal bridges if not well designed and executed. In this paper, the LSF construction system is described and analysed in order to show its main advantages and drawbacks. The assessment of embodied and operational energy is essential to perform a life cycle analysis. The reduction of both energies consumption is crucial to increase the sustainability performance. Special focus is given to describe and exemplify several strategies for improvement of thermal performance and energy efficiency of LSF buildings.

1 INTRODUCTION

The demand to reduce the energy consumption in buildings and to use recyclable materials has increased in the last decades. These concerns have the intent to create a more sustainable environment. In Europe, buildings are responsible for 40% of the energy consumption, having the space conditioning (heating and cooling systems) an important share, which also depends on climate (Santos et al. 2012). Given the high energy consumption of the buildings, the European Union established several objectives in the Energy Performance Building Directive (European Directive 2010/31/EU) regarding "nearly zero-energy buildings" for the year 2020. It is defined that not only must be increased the contribution from renewable energy sources, but also must be performed an improvement of buildings energy efficiency.

In recent years, alternatives to traditional structural systems for buildings have emerged, e.g., lightweight steel framing (LSF) systems. The LSF construction systems have as base-material a steel structure, made of bended cold formed steel plates. Usually these elements are prismatic and have a thin-walled cross section.

Given the advantages of steel structures (e.g. cost efficient; reduced weight; exceptionally solid in relation to weight; excellent stability of shape in case of humidity; rapid on-site erection; easy to prefabricate; great potential for recycling and reuse), the use of steel as a construction material has seen a phenomenal growth in the last few years, being used with success in many industries (e.g. office and also residential buildings). However, if not correctly addressed, thermal bridges are a significant drawback with some difficulty of resolution, which could penalize the thermal behaviour and energy efficiency of steel buildings. In recent years, there has been an effort to assess and improve the thermal behaviour of constructive solutions with steel structures.

In this paper the LSF construction system is described. First, the three types of LSF construction, depending on the thermal insulation position, are presented. Besides, the main advantages and drawbacks of this construction system are explained. Next, the main issues regarding the thermal performance of LSF construction elements are presented, including: the thermal bridges relevance and mitigation strategies; the thermal inertia importance and improvement measures, and; operational energy mitigation measures depending on the climate. Finally, a case study about LSF wall thermal performance assessment (numerically and experimentally) is presented.

2 LSF CONSTRUCTION SYSTEM OVERVIEW

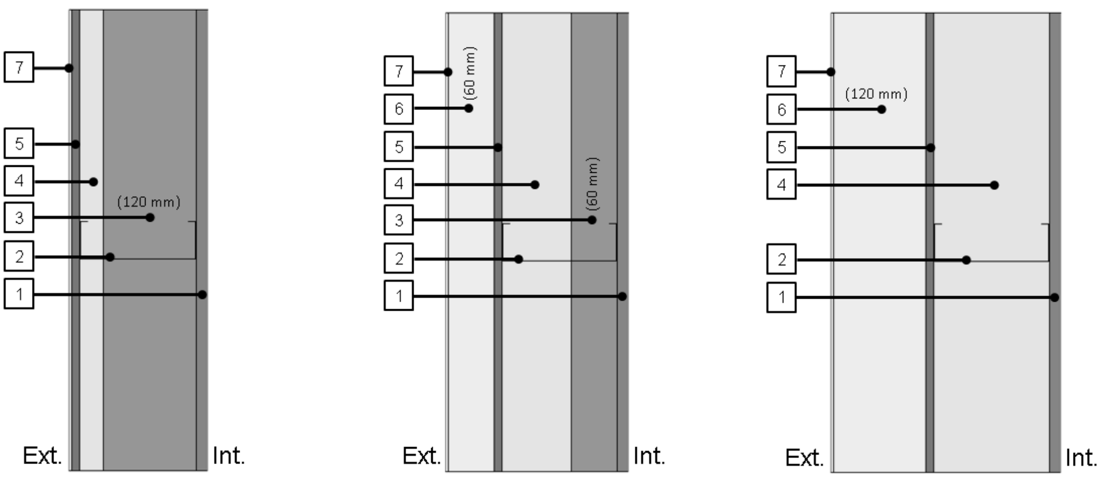
2.1 *Classification of LSF construction elements*

The LSF construction elements (e.g., walls) can be classified in three types, depending on the position of insulation materials. In Figure 1 are shown examples of cold, hybrid and warm frame construction, which depends on the position of the insulation materials. The presented examples differ in the position of the wall materials: gypsum; Lightweight steel frame (LSFrame); stone wool; OSB (Oriented Strand Board); EPS (Expanded Polystyrene); ETICS (External Thermal Insulation Composite Systems).

In cold frame construction all the insulation is included within the thickness of the steel, being the insulation layer crossed by the steel studs. Figure 1a) illustrates this configuration. This type of construction is not recommended for cold climates, given the lower temperature inside the wall there is a higher risk of occurring interstitial condensation, especially in the steel studs and its vicinity.

Figure 1b) shows an example of a hybrid construction, in which the insulation is placed between the steel frames. The thickness of external continuous thermal insulation should be maximized for better thermal bridges mitigation.

In the third type, warm frame construction (Figure 1c), the insulation is all placed outside of the steel framing. This is the best option, reducing the risk of interstitial condensation and maximizing the thermal mass of the building envelope.



a) Cold frame construction b) Hybrid construction c) Warm frame construction

Figure 1. Classification of LSF constructions, depending on the position of insulation materials (Santos et al. 2012). (Materials: 1-Gypsum; 2-LSFrame; 3-Stone wool; 4- Air gap; 5-OSB; 6-EPS; 7-ETICS)

2.2 *Advantages*

The LSF construction system presents great potential for recycling and reuse and several advantages when compared with other types of construction systems. The reduced steel debris in the construction phase and the steel removed during the demolition phase can be totally recycled and/or reused with evident sustainability advantages.

These construction components, also provide other advantages: reduced weight with simultaneous high mechanical strength; prefabrication in large-scale of substructures and subsequent assembly on site, which allows to have shorter assembling time; higher quality control; no dimensional variations caused by moisture; architectural flexibility; and low cost.

From the point of view of environmental impacts, this construction technique allows the adoption of sustainability policies that enables the long-term conservation of natural resources, harmonizing the relationship between natural environment and human construction.

Regarding economic issues, the use of modular LSF construction systems provides many benefits, given the increase of construction speed allied to the production in scale and to superior quality achieved by factory-based quality control. In comparison with traditional masonry construction, LSF construction is environmentally less sensitive since the weight of the construction is lower and the disruption on site is reduced. Factory production is also less wasteful and most of the building components could be easily separated and selected for recycling at the end of the building's life.

The recyclable potential of the materials used in LSF construction and its higher durability is also an economic advantage. In the particular case of steel, this material recyclability and reuse rate is often higher than 95%. In addition at demolition stage it is also a better solution, due to the possibility of applying screw connections, allowing for quick and easy dismantling.

Another advantage of using LSF modular systems is the decrease of work accidents, in the construction site, due to the lightweight elements and type of assembly.

2.3 *Drawbacks*

One of the main drawbacks of LSF construction elements is the high thermal conductivity of the steel, which can create thermal bridges, whenever its design is not adequate, being important to use continuous thermal insulation (e.g., ETICS). Thermal bridges could penalize the thermal behaviour and energy efficiency of steel buildings, if not correctly addressed, increasing energy consumption and costs during the operational phase. Other related problems associated with thermal bridges, are the constructive pathologies and reduced levels of comfort and salubrity associated with the occurrence of condensation phenomena driven by localized temperature drop inside construction elements. This is particularly important in buildings where the relative humidity (RH) may be high and can greatly decrease the materials durability.

Another potential drawback of LSF construction system is the low thermal mass and consequent thermal inertia, leading to higher daily temperature fluctuations, originating higher discomfort to the occupants and higher energy consumption. This is particularly evident for climates with higher daily temperature swings, e.g., Mediterranean climates.

In the next section will be described several available strategies to mitigate this potential drawbacks of LSF construction.

3 THERMAL PERFORMANCE OF LSF CONSTRUCTION ELEMENTS

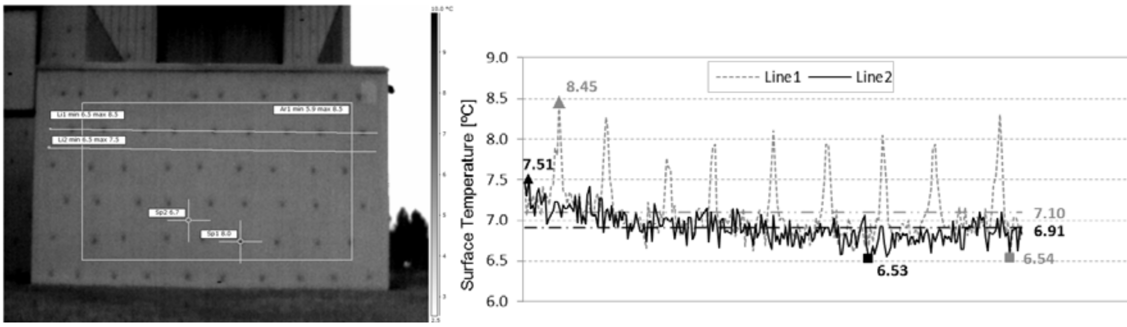
3.1 *Thermal bridges relevance*

Thermal bridge is the term commonly used to describe localized phenomena where there is an increased heat transfer in the building envelope, showing a reduction of thermal insulation effectiveness. These leads to a higher heating energy need/use and are becoming especially important in high performance buildings. Here, the energy loss due to thermal bridges can be even higher than, for example, the energy benefit provided by thermal solar collectors for domestic hot water production. The total impact of thermal bridges on the heating energy demand is significant reaching 30% and is greater than on cooling energy demand (Erhorn-Klutting et al. 2009).

Thermal bridges have two important consequences compared with unabridged structures: a change in heat flow rate; and a change in internal surface temperature (Mao et al. 1997). Normally, the effect of a structural element in contact with exterior envelope may cause a "thermal bridge", i.e., a fast and easy path for conducting heat. The problem of thermal bridges is delicate and extremely inconvenient, and may compromise the effectiveness of any applied insulation system. During design stage, often the effect of thermal bridges still remains as an issue that is neglected or superficially considered in the assessment of buildings thermal performance.

The Canadian Sheet Steel Building Institute (CSSBI) conducted a comparative study of thermal performance between steel and wood framed house, located on the same street, and inspected them on the same evening with an outside temperature of 6ºC, and no wind. The study demonstrated that at long-term the wood presents moisture contents and fissures that may cause air infiltration, increasing heat loss. Because steel does not warp or shrink in contact with moisture, therefore, steel have here a clear advantage, allowing heat loss minimization and energy conservation. “When detailed with insulation and expanded foam insulation in the stud cavities, the steel homes used 7% less energy than their wood counterparts which were built to the same nominal R-value” (CSSBI 2008).

As previously mentioned the use of external continuous thermal insulation is an important thermal bridge mitigation strategy. However, special attention should be given to the selection of the thermal insulation fixation technique. The glued one should be preferred. If mechanical fasteners are adopted they should be for instance in PVC material rather in Steel. In Figure 2 is showed an infra-red (IR) thermography image of LSF in a building façade, where is visible the rise of temperatures in some points of the wall due to the use of steel fasteners to fix the ETICS. This localized surface temperature rise is well visible in Figure 2b).



a) IR Photo. b) Surface temperature along lines 1 and 2.
Figure 2. Building façade IR thermography image and temperature graph.

The mitigation of thermal bridges can be achieved with simple design rules and strategies. Some examples are: keep the façade geometry as simple, as possible; avoid the interruption of the insulating layer; at junctions of building elements, the insulation layers must be joined at full width; when the interruption of the insulation layer is unavoidable, a material with the highest possible thermal resistance should be used; openings, such as doors and windows, should be installed in contact with the insulation layer (Santos et al. 2012).

Next are presented and described several techniques that can be used to mitigate thermal bridges, particularly focused on steel buildings.

a) External continuous thermal insulation

As previously mentioned, the use of continuous exterior thermal insulation is an effective way to improve the thermal performance and reduce the thermal bridges. Also the increased spacing between profiles allows a thermal resistance increase (higher R-value). Kosny et al. (1995) showed that the gain in R-value caused by the increased spacing was about 20% with 1.3 cm of EPS and about 15% with 2.5 cm of EPS.

b) Increasing the heat flux path

The increase of the heat flux path through the reduction area of the steel profile, with the insertion of slots in the web stud is an efficient way to reduce heat flow. Besides, if the flange length is decreased, the U-value will also decrease.

c) Reduction of the profile flange contact area

Another possible solution is to use a profile with a geometry that allows reducing the contact area of the flanges, creating a thermal break, thereby increasing the wall's R-value. This system is a patent developed for thermally improved exterior wall framing (Thermachannel 2013) and allows an improvement on the R-value of the wall (until 16%).

d) Thermal breaks for building components
The introduction of thermal breaks, allows the creation of a barrier in the thermal transmission between external components and internal of building. Thermal breaks can be incorporated in steel structures allowing simultaneous transmission of high loads.

e) Thermal Break Strips
The placement of insulation material applied locally along the studs allows the mitigation of thermal bridges. This solution consists in the placement of insulation strap attached to steel framing using button screws or an adhesive.

3.2 *Thermal mass relevance*

The building envelope thermal performance is crucial to provide a good thermal behaviour and energy efficiency, allow reducing operational energy. As mentioned earlier the LSF buildings have low thermal inertia. To change this scenario there are several strategies to increase thermal mass, such as: use external insulation; use massive construction materials; take advantage of huge ground thermal mass; and use phase change materials (PCMs), as described next.

a) Use of massive construction materials
The use of massive construction materials in LSF buildings is none usual, however there is some simple strategies that allows increase the mass of the building. In Figure 3a) is shown a stone wall used to store energy obtained from solar gains through glazed windows.

b) Use of ground thermal mass
A geothermal energy system allows to use the enormous ground thermal mass, taking advantage in summer and winter seasons. These systems can be based on air, such as present in Figure 3b) or refrigeration liquid.

c) Use of phase change materials
PCMs are also a great solution to increase the thermal mass. They have the great advantage of heat storage, acting as a heat buffer, due to the latent heat. There are several types of PCMs, with different heat store capacity, shapes, fusion temperatures, macro- and micro-encapsulated. Figure 3c) shows one example.

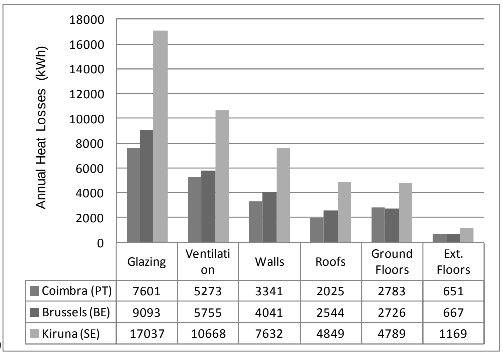
Figure 3. Thermal inertia improvement: a) wall filled with stones (Detect Energy 2013); b) ground heat exchanger air circulation pipes; c) PCM panels (DuPont 2013).

3.3 *Operational energy*

The reduction of operational energy used in buildings, maintaining the internal comfort is essential to achieve a better building sustainability label. This can be accomplished with good design and construction techniques. The best way to test different improvement design solutions is performing advanced dynamic thermal simulations of the building, using the climatic data of the site. This will allow, for example, to achieve a good compromise between putting too much thermal insulation (higher embodied energy) or too little (higher operational energy), towards the optimisation of resources.

Santos et al. (2012) performed advanced dynamic simulations studies (DesignBuilder, EnergyPlus) that allow assessing the importance of the improvements in the building envelope main components. Figure 4a) shows, in relative terms, the importance of each building component regarding the annual heat losses through the building envelope, for three locations: Coimbra (Portugal); Brussels (Belgium); and Kiruna (Sweden). In the colder city (Kiruna) the glazing and ventilation system have the major importance in the heat losses, evidencing the necessity of improving it.

Figure 4b) shows the heating annual fuel breakdown decrease due to improvements in the envelope components, for the building located in Kiruna. Comparing the initial solution with the improved final one, it was obtained a reduction in energy demands of 57%.

a) 

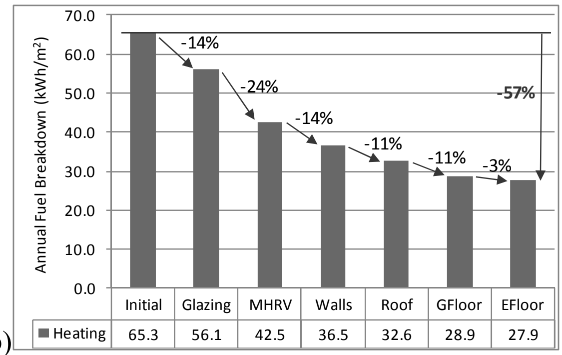
b) 

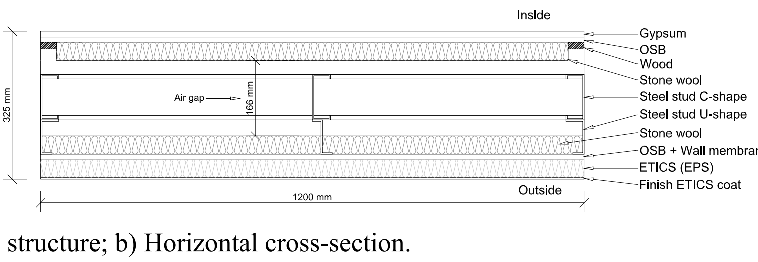
Figure 4. Operational energy: a) Annual heat losses through building envelope main components; b) Heating annual fuel breakdown decrease due to improvements (Santos et al. 2012).

4 LSF WALL CASE STUDY

In this section is briefly presented a case study regarding a modular LSF wall in order to assess the importance of some thermal bridges mitigation techniques. The modular wall is comprised of a steel structure containing galvanised steel cold-formed studs with different cross-sectional shapes: "C" (100x40x10x1), "U" (75x40x10x1) and "Z" (75x25x1). Each wall module is 1.2 m wide and 2.49 m high. Figure 5a) illustrates the assembled steel structure contained in the wall and Figure 5b shows the enclosed materials and thickness.

Having as reference a standard LSF wall, three design improvement measures were implemented and the increased performance of the wall quantified. All the numerical results were obtained from wall models assembled in Ansys CFX finite element software.

In Table 1 are presented the models description and obtained results (U-value). The first improvement strategy was the insertion of a thermal break strip of rubber between the steel and OSB panel, on the outer surface. This allows a decrease of 1.9% in the U-value (in comparison with the reference case). The second approach was the use of vertical slotted steel profiles, with removal of 14% of web stud mass. The benefit from this solution is similar to the previous one (-1.87%). In the last simulation, was applied polyurethane filling the air gap and replacing the stone wool. As expected this solution significantly improves the U-value (-86.45%). Although this good thermal insulation improvement, this solution may have a functional drawback related with the lack of an air gap, if and whenever there is a moisture infiltration.


a)


b)

Figure 5.Wall module: a) LSF structure; b) Horizontal cross-section.

Table 1. LSF wall case study results.

Model description	U-value W/(m^2.K)	Decrease of U %
Normal wall	0.3011	----
Use of 10mm rubber between the steel and OSB, on the outer surface. (λ_{rubber} = 0.037 W/(m.K))	0.2954	-1.90
Slotted steel profiles, removal of 14% of web stud mass.	0.2955	-1.87
Use of polyurethane replacing stone wool and filling the air gap	0.1615	-86.45

The IR thermography can be used to assess the temperature surface distribution and evaluate if there is any thermal bridge effect. Figure 6 was obtained during an experimental test of a LSF wall before applying the external thermal insulation (ETICS). As expected, the location of the vertical steel studs can be clearly identified, showing a higher surface temperature in the vicinity of the vertical steel studs due to the increased heat flux through the steel.

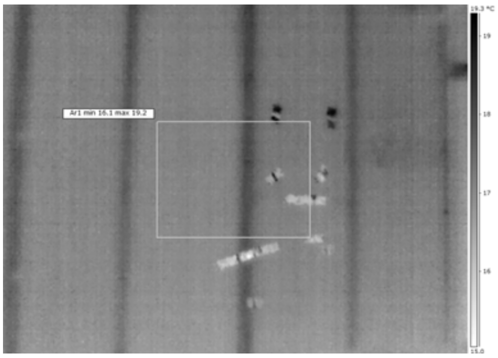
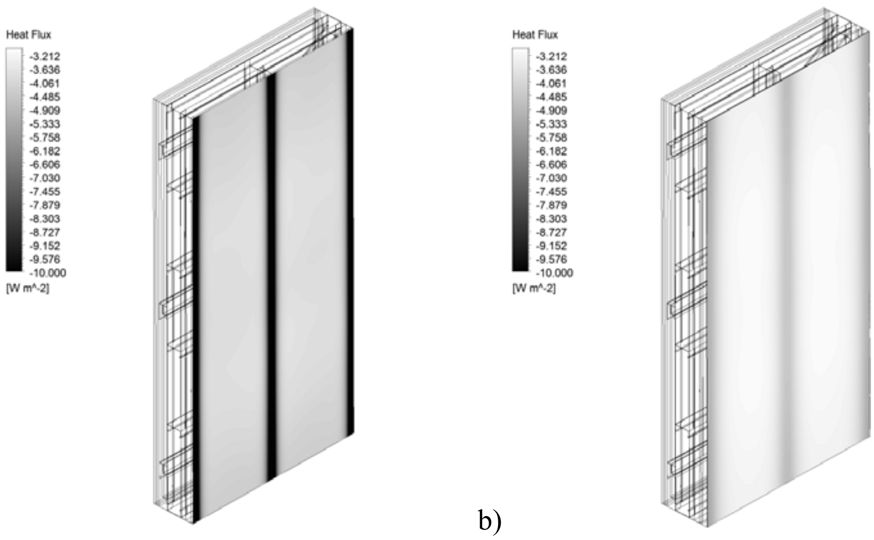


Figure 6. Infrared thermal image of a LSF wall without ETICS (external surface).

The numerical results also show the surface temperature and heat flow increase due to the steel studs. Figure 7 displays the heat flux on the LSF wall external surface before and after the ETICS assembly. The external thermal insulation allows a significant reduction in the heat flux (Figure 7b) in comparison with the one without ETICS (Figure 7a). This fact leads to a more homogenous wall surface heat flux distribution, and thus, a better thermal behaviour. Notice that the negative heat flux values means that this wall surface is losing heat (cold surface). Therefore, the highest heat flux absolute values are in dark and the lowest are in grey / white.



a) b)

Figure 7. Heat flux predictions for the wall exterior view: a) without ETICS; b) with ETICS.

5 CONCLUSIONS

In this work the main advantages and drawbacks of LSF construction system were described, being evident a huge potential towards sustainability. However, the adequate design is essential to achieve this high sustainability level, for instance minimizing thermal bridges and improving thermal inertia. These two parameters may have a big influence in thermal behaviour and energy efficiency of LSF buildings. Several strategies are nowadays available to address these issues, as presented in this paper. Some of these techniques can be applied alone or simultaneously, being these specifications very important at design stage to minimize operational energy, increase energy efficiency and sustainability label.

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Assessment and monitoring of a student residential building using an innovative execution solution

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ABSTRACT: The construction, fit-out, operation and the final demolition of buildings contributes to a large-scale negative impacts on the environment, even at the level of material and energy consumption, or even because the inefficient infrastructure. This document is based on a thorough study that encompasses the design phase, construction, use and, finally,the end of life. This work it is followed by an innovative modular building and execution process, within the FRAMEUP project, which will be take place in Lulea, Sweden. The aim of this study is to analyze the sustainability of this future building; first from an energy point of view so as to know the specific energy consumption using specific software, and on the other hand from an environmental stand point by leading a complete life-cycle assessment (cradle-to-grave).

1 INTRODUCTION

World's population reached 7 billion inhabitants in 2011 and is expected to increase until 9 billion until 2050 (UNEP, 2011). This growth of society and technological development without planning suitable introduced the world to a serious problem: environmental degradation and the extreme inefficient use of energy. To decrease the impact caused by the activities purposes, as human activities, appears the new concept of sustainable construction.

Building construction industry consumes 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases (Asif et al, 2007). Throughout the use time of the building, half of the energy used goes through the heating, cooling, ventilation, and lighting, designs that co-opt natural forces to do the same thing are the biggest way to reduce the environmental impact of new buildings and to save money. Position of the windows to capture sun during winter, along with insulation and airtight construction, can cut heating needs more than 97%(Lenssen, 1995).Similar techniques can eliminate air conditioners in hot climates. Simply planting trees near buildings can cut cooling needs up to 30%. All this can be achieve by making a correct design of the structure to predict all this parameter, thus the design assess: location, orientation, specification of the fabric, materials chooses, thickness of the walls, would be possible to achieve greatly the decreasingof energy profiles.

Regarding to construction materials and products, it is important to define a life cycle study to improve environmental performances of the building in the analyzes , including construction works as well, dueto the waste, transportation, energy consumption to erect the building. Construction products can be nowadays be change by ecological, environmental friendly ones that will significantly contribute to reducing a building's environmental impact throughout all its lifetime.

The quality of the internal environment of buildings is an essential element to the health of its occupants (Organization, 2009). Bio-climatic considerations and good ventilation can also reduce or even eliminate the need for air conditioning in the summer months whilst reducing the amount of energy required for heating in the winter.

In order to facilitate the interpretation of the results regarding with a complete sustainability study, sustainability assessment methods have been developed withinthe Member States, European Centre of Normalizationon the Technical committee, CEN TC 350.Thatestablished standardized methods for assessment of sustainability aspects of both new and existing constructions, since May 2005.Based on the work of CEN TC 350, research work, and different tools provided, this paper will give an overview of how the sustainability assessment can be applied to this new construction. (CEN/TC 350 Sustainability of construction works, 2012)

2 MODULAR STEEL CONSTRUCTION AND THE INNOVATIVE EXECUTION

Modular buildings are sectional prefabricated buildings or houses that consist of multiple modules manufactured in a remote facility and then delivered to their intended site of use,ensures better construction quality management and faster construction either.(Institute, 2000)

One big benefit it is the possibility of producing and transported according to the assembling phase in the work site, reducing the space needed in situ. The modular production in factory reduces significantly the work outdoors and similarly reduces the assembling to a minimum. This can contribute to a shorter construction period, reducing labor, financing and supervision costs.

The modular construction presented here is based on a steel skeleton, where the modules will rest. Each module has a "plug-and-play"system, i.e., it is fully equipped which permits that, once assembled and plugged, it is ready to use. Remains parts to be assembled are corridors floors, stair case, façade and roof (Andrade, 2010).

The innovative execution process reliesmost of all on the concept of starting the assembling of the building from the roof to the lower floors. The existence of a rigid frame, designated as Grid, permitsthe liftingof the building, promoting, each time the building is lifted, a clearance on the ground levelenough to assemble the next lower floor from bellow.

Figure 1: Example of the lifting stage.

Every floor will be assembled under the previous one. When all parts are assembled and details installed in each floor, the grid it is lifted up, creating below the clearance for the assembling of the next floor.

In this method all the labor is carried out at ground level and consequently without the use of crane. To make this possible, attached to the structure there is a lifting system. This system must be able to lift up the structure and simultaneously support horizontal loads, avoiding an exaggerated swinging, and ensuring the structure integrity during construction (Andrade, 2010).

The lifting system is to be considered as a "tool"in which is prepared to be used in other buildings.Thus for each building erection, the lifting system it is assembled previously and disassembled in the end of the execution phase. The same principal, as used in the raising of the building, can be considered for dismounting the building and, once again, the lifting system it is assembled and disassembled in the end of this operation.

3 ENERGY PERFORMANCE IN BUILDINGS

Improving energy efficiency in buildings is one of the most cost-effective ways across all sectors to reduce energy consumption and hence greenhouse gas emissions (Agency, 2008).
For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature, reducing energy demands and through time the owner will save money with this improvement.

Energy certification increases awareness of energy consumption and enables consumers to compare buildings, thereby providing to builders with an incentive to improve energy efficiency in buildings. In majority of the cases this improvements have some extremely initial costs but the owner will have to think in a long-term line, because a pay-back time in this case maybe exceeds what they would perceive as a good return on their investment.A key part of this legislation is the Energy Performance of Buildings Directive (Directive 2002/91/EC,EPBD), first published in 2002, which required all EU countries to enhance their building regulations and to introduce energy certification schemes for buildings. They established that by 20120 all new building will be nearly zero-energy consumptions.

Common standards have been developed to support harmonization in Europe (through the European Committee for Standardization [CEN]) and in North America through the Residential Energy Services Network (RESNET) program. These programs also reflect international standards contained in the International Energy Conservation Code (IECC), those of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and those developed by the International Organization for Standardization (ISO).

Assessment methodologies to reach the lowest energy value generally uses software tools to calculate energy performance and ratings systems to classify, often based on annual energy use in specific terms, such as the number of kilowatt hours used per square meter (kWh/m^2/year).

To modulate the building was used the Design Builder software, an advanced graphical user interface that has been specially developed to run EnergyPlus simulations. DesignBuilder attaches the reliability and stability of EnergyPlus to perform accurate thermal analysis of buildings. The interface facilitates the user in constructing the building geometry and especially in setting up: heating/cooling technologies; occupancy types; lighting and construction materials.
Visualization of results provides a quick overview of data. Graphs, energy consumption pro les and weather conditions are automatically generated at the end of the calculation.

4 LIFE CYCLE ASSESSMENT

For a building designer, conducting a LCA helps to identify the environmental impacts of the building, including detailed knowledge about the contributions from various parts of the building and guaranteeing that the design can be improved leading to the least as possible impact in the end.

LCA is the procedure that allows analyzing, formally, the complex interaction of a system - a material which may be a component or set of components - with the environment, along its entire life cycle (Bare et al, 1999; 2000). Characterizing, what became known as the focus of, the cradle to grave- study that includes all the stages since the production until the end life. LCA assumes thatall life stages of a product, which generates environmental impacts, are analyzed.

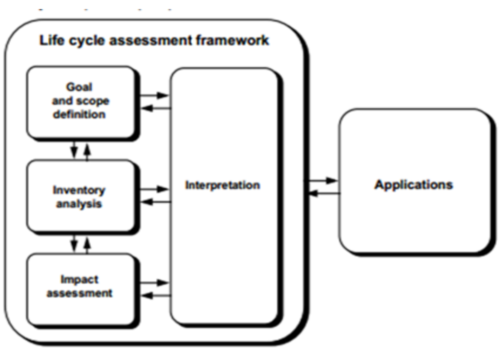

Figure 2: Methodological phases of framework of an LCA (ISO 14040, 2006)

Possible contributions of LCA in every moment of the life cycle (Centre for Design, 2001) may be the following:

• Phase idea and concept: the initial phase (Phase 0), pre-assessment and concept phase (Phase 1) Summary of project objectives.

• Design (Phase 2): this stage is carried out a briefing of the project, which by itself has little impact, but it is here that the consequences of the life cycle of the building on the environment are mostly determined by the LCA tools need be applied extensively. Nowadays becomes one of the most important phase because designing the structure applying tools to preview the use, the sun light, the ventilations systems, will be possible design in better way to minimize all the future loses.

• Construction of Building (Phase 3): The greatest impact of this phase is related to material consumption and waste production.

• Operation (4^{th} stage): this is the stage in which the owner or user uses the building. The most important impacts of this phase are related to energy expenditure and possibly with the expense of water, being also consider the production of waste. At this stage, it is important that the guidelines on maintenance and operational management are followed.

• Maintenance (Phase 4b): the most important impacts of this phase are based on the materials chosen for the renovation of the building over its lifetime. Here, the guidelines on materials, LCA tools and design / project should be implemented.

• End of life (Phase 5): at the end of life of the building, or demolition phase, the guidelines are more appropriate to assist in the reuse, recycling and landfilling of building components, the most efficient way.

5 CASE STUDY

The Pilot Building consists of a three-story-buildingplanned to be built in the city of Luleå, Norrbotten country of Sweden, in Luleå University of Technology Campus.

Figure 3: Future location of the Pilot Building (65°37’11.13”N 22°08’21.16”).

The superstructure is composed of S355J2H hot rolled steel profiles and the modules with lightweight steelcassettes in the walls and ceiling and a concrete slab on the floor.

The external structure will have 11.5 meters high including the slab foundation, around 13.5 meters long and 13 meters width, so the external volume will be 20.15 m3.The building is composed by 8 modules in each floor. Each module can be connected to the next one, creating a bigger apartment. Thus the building is constituted by 9 double modulesand 6 single modules, creating 15 apartments.Each single module will have an area of 10.41 m² and each double module will have 20.81 m²; the area corridorsit is 23 m². Therefore taking into account that only the rooms and corridor will be occupied we will have an energy reference area of 318.75 m².

Figure 4: Scheme of the modular building, hereby considered only with the skeleton and modules.[Pedro Andrade]

5.1 *Composition of the Modules*

In this modular building the modules will be resting in the steel skeleton. Every double module will be located between columns consequently there will be a space between two consecutive double modules. The way to model this particularly building in the software it is completely different from the traditional way. The building should be modeled in order to be consistent with the real architectural geometry. The traditional exterior walls were used to model the curling wall facade whereas indoor partitions were used to model the walls of the module, creating a anair gap between both.

According to the insulation of the building, it is completely different from the regular way; each module has its own insulation and ventilation system. The exterior shell of the module is made up of interconnected 400 mm wide cassettes (1 mm steel plates). Attached to the cassette walls there are two gypsum boards (15 mm x 2) and 50 mm of rock wool inside cassettes.The walls of the modules are not very well heat insulated because the main purpose is to guarantee a good sound insulation and fire protection of EI60 between apartments. The rock wool has both good acoustic and fire properties and the two layers of gypsum board create a fire barrier to protect the steel structure. The floor of the modules is composed by a concrete slab (average thickness of 60 mm) that is enclosed in aframe made of a steel rectangular hollow section beam.

Therefore the modules have a gap between them on the same level and between floors. This special geometry was considered in model by introduction fictitious “floors” (approximately 50 cm high) between real floors and small spaces between modules in order to simulate the clearances between elements.

To enclose the building will be placed a façade of EPS of 250 mmthickness of the sandwich panels to ensure the thermal insulation and the tightness of air, water and noise to respect the Swedish building regulations.

The U-values of the different walls were calculated on the Design Builder software.These values were given for two situations, with and without thermal bridges, generated by the gaps between modules and façade.

6 RESULTS

6.1 *LCA*

The selection of environmental impacts over environmental aspects in this study is justified by two main reasons. First of all, impacts give a clear notion about how much environmental damage is really caused during the total life span of the building. On the other hand the environmental aspects indicators must be further analyzed to really evaluate their effect on environment. But the main motive is that the data regarding aspect indicators is not complete for all the products or processes.

The calculation methodology uses various indicators to account for all the environmental impacts and aspects of each product and process applied to the whole building. The results obtain can be seen in the Figure 5, where the total amount of emissions is calculated for40 years of life time of the building.

The methodology to obtain the values is based in the official EPD of each product/process used, multiplying by the amount of the products/processes used in all building, as can be seen in the next equation, using GWP parameter as an example in equation (1):

(1)

- is the global warming potential quantified for the life cycle stage *i*of the building;
- is the gross amount of product or service *n* used in the life cycle stage *i*of the building (n = 1,2, 3, …, N)
- is the global warming potential of product or service *n* used in the life cycle stage *i*of the building (n = 1, 2, 3, …, N)

The Figure 5presents the results to the indicator of Global Warming for all the stages of the building.The results presented are according the system boundary chosen; Cradle-to-grave.All the inputs and outputs are considered for all the phases of the life cycle.The figure 6 shows all the environmental indicators per stage of the building.

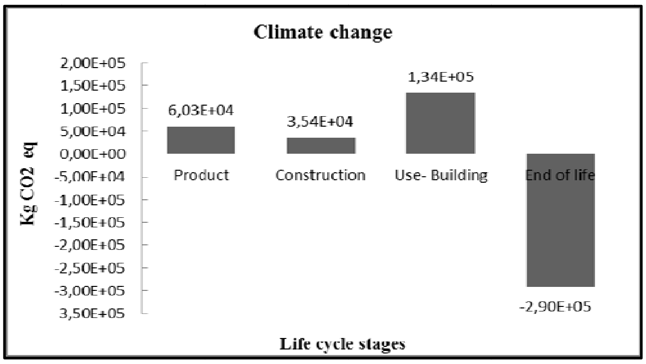

Figure 5 - CO_2impacts by stage for all lifetime of the building

	Climate change (C02 eq)	Destruction of the stratospheric ozone layer (CFC-11 eq)	Acidification of land and water resources (SO2 eq)	Eutrophication (PO4 eq)	Formation of ground level ozone (C2H2 eq)
■ Product	6,03E+04	9,46E-03	1,77E+03	4,73E+02	1,74E+02
■ Construction	3,54E+04	9,93E-03	3,29E+02	1,09E+02	5,54E+00
■ Use-Building	1,34E+05	7,73E-03	1,73E+03	4,25E+02	1,77E+02
■ End of life	-2,90E+05	-9,88E-01	9,27E+04	-5,33E+04	-2,68E+04

Figure 6 – Environmental impacts by different stages of the building

6.2 *Energy*

According with National Board of Housing, Building and Planning's building code (BBR),in Sweden, the building's energy usedcorresponds to the total energy per year that need to be supplied to a building for heating, comfort cooling, hot water , lighting and all the auxiliaries that the building needs. This energy,once divided by reference area, will give us the building's specific energy use that will be expressed in kWh/m^2 per year (see the results in Table 1).

This reference area includes all the internal building spaces that will need to be heated more than 10 ºC. So to be more accurate will be all the conditioned areas of the entire building

To set limits to the energy use, Sweden is divided into three climatic zones: south, center and north,with different energy criteria. There are different requirements for residential buildings and commercial buildings, and whether the building is planned with electric heating or other heating systems:

- Climate zone I -Counties of *Norrbotten*, Västerbotten, Jämtland.
- Climate zone II- Counties of Västernorrland, Gävleborg, Dalarna and Värmland.
- Climate zone III- Counties of Västra Götaland, Jönköping, Kronoberg, Kalmar, Östergötland, Södermanland, Örebro, Västmanland, Stockholm, Uppsala, Skåne, Halland, Blekinge and Gotland.

Table 1 - Total energy consumption of the building.

	Specific energy use	Energy use	
	$kWh_{FE}/m^2.y$	$kWh_{FE}/.y$	%
Heating	36.8	11695	36.1
Cooling	3.4	1084	3.4
Hot water	38.9	9049	38.2
Lighting	9.8	3376	9.6
Auxiliaries (fans, pumps, auto control devices)	13	4144	12.7
Total building	101.9	29348	100

The final value of specific energy use will be 101.9kWhFE/m².y, which means that the building is 21.6% better when compared with the Swedish regulation that sets 130 kWhFE/m².y as a limit to residential houses in the climate zoneI(zone where the building will be built).

7 CONCLUSION

According to the use stage, the energy studied, fulfills the Swedish requirements.The building has a good performance, however nowadays it is possible to achieve an even lower consumption.Unquestionably, Operational Energy is the major source of impacts (for climate change) from an entire building life-cycle perspective. That is expected because the operation energy takes into account the energy plus the water in the use time.As we know the use of energy is the non-friendliest environmental process, which a house or an industrial process has.

So this study confirms that is vital to improve the performance throughout the operational phase. To reduce fluxes (energy, water and waste) during the utilization phase seems to be the first action to achieve, in order to improve the performance of the building. To have a decrease of impacts in this phase, in many countries is usual to decrease the Operational energy, by increasing the insulation thickness and air leakage protection, which will lead us to a very low or even zero-energy house in the future.

The modular construction has vast benefits: economic, social, energetic and environmental,due tospecific away of construction. The modular production in factory reduces significantly the work outdoors, so that allows better control of emissions, better efficiency of time and accurate dimensions. This have more benefits even in the constructions phases, because of the short time of construction, that allows the use of less machines, less energy used to this process, and less emissions that in the normal constructions is the higher problem. Also with this innovative constructions system we expect to reduce time, costs and environmental impacts.

The FRAMEUP project works with other partner from different places in Europe. This building complains a structural challenge but also contributes for the sustainability issues. Within this project, the building will be monitored in all phases of construction and use-building and the sustainability models will be calibrated according to the data collected in the building.

This pilot building it is intended for testing new construction products (for example new facades elements or roof elements), creating a real scale situation. The results shall be compared with data obtained in the other "research" buildings like in Aachen and Coimbra, which are part of the FRAMEUP partnership. Therefore with the data collected from thesethree building, itis possible to cover the Europe's major climates and consequently get a better picture of the sustainability issues.

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Chapter 6

Building Sustainability Assessment Tools

Space design quality and its importance to sustainable construction: the case of hospital buildings

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ABSTRACT: The hospital project, more than any other, requires a number of concerns related with the satisfaction and well being of working teams, patient, administration and other officials. In this context it is possible to say that the healthcare spaces design are fundamental for the best work, functionality, results and to improve the best practices for a sustainable building. The volume and organization of these spaces are very important and can be decisive in environmental, economic and social development of the whole building. Therefore this study is is focused in the space design quality and how its organization, flexibility and adaptability can be fundamental for the well being of people and for the best results in the sustainability of construction and will highlight how building sustainability assessment tools consider and evaluate these aspects. It is fundamental to propose the best way to promote the investment in the hospital design space to support the design team in the adoption if space solutions that contribute to the sustainability of these buildings.

1 HOSPITAL BUILDINGS

1.1 *The architectural influence*

In Europe, approximately 10% of the GDP of each country is used in healthcare buildings and, according to the 2008 data, this type of constructions contributes about 5% of CO_2 emissions from European Union Countries (Vaquero, 2013). The intensive use of energy resources, water resources, waste production, etc., in the hospital buildings brought this type of buildings to the discussions in the field of sustainability. However, today, reality shows that there are still some hospital's management units that do not give attention to the efficiency of these buildings and to the implementation of better practices. Fortunately, there has been in Portugal, and in many other countries, an awareness of the relevance of these issues and the need to increase the efficiency of these buildings.

Early environmental design initiatives were focusing only on the reduction of energy demands. Different institutes and governmental initiatives developed tools and policies to address this problem. In 1980s and 1990s some of the initiatives began to reflect concerns about the sustainability of the construction industry, and in 1993 the UIA/AIA Word Congress of Architects concluded that it was a bold challenge to the profession of an architect to put a broader sustainability agenda into practice (Guenther & Vittori, 2008). In 2000 many of these initiatives turned to incorporate sustainable design strategies as basic and fundamental in standard practice. In 2005, the American Institute of Architects (AIA) established a more aggressive position on the responsibility of design professionals, defending the position that the architects must change the professional actions and work together with the clients changing the actual paradigm of designing and operating a building (AIA, 2005).

The sustainable project requires a revolution in the way of thinking the building design. So it is important that this transformation, that across all phases of the life cycle building, will be reflected in the early stage of architectural design and in the essence of it: the design and organization of space. If the architectural design should consider the whole patient and users' needs, environmental concerns and generate synergies among all actors of the design team, then this should be directly addressed in building sustainability assessment tools. This is essential in order to support architects during the early phases of design and to recognize the efforts of an architect in designing a truly sustainable building.

Michael Lerner (2000) formulated the following question: "*The question is whether healthcare professionals can begin to recognize the environmental consequences of our operations and put our own house in order*" (Roberts & Guenther, 2006). This is not a trivial question, but the foundation of all other issues that may arise around this same concern (Roberts & Guenther, 2006). Based on this, Figure 1 illustrates the relationship between human health, medical treatment and environmental pollution that directly affects the mission of the healthcare industry.

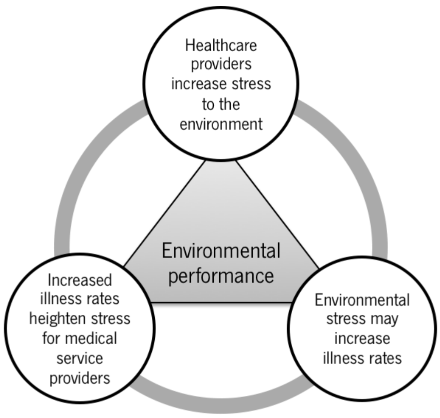

Figure 1. Relationship between environmental performance and healthcare (Roberts & Guenther, 2006)

1.2 *Space design quality*

Several studies and professionals agree that it is possible to work through the weaknesses of actions and measures, some of them simple and inexpensive, but capable of reducing the environmental impact. In order to introduce sustainable practices in the design of healthcare buildings, several countries have published guidelines to promote improved design approaches. Among them, it is possible to highlight recommendations for hospital projects that the Green Building Committee of the American Society of Healthcare Engineering (ASHE) published in 2002 (Robert & Guenther, 2006). This partnership between the American Hospital Associations and the United States Environmental Protection Agency, pointed out the principles of sustainable architecture that are intended to reduce waste and other impacts associated with hospitals (Robert & Guenther, 2006). The ASHE proposes an architectural development of these recommendations in order to develop buildings capable of improving the health concerns at three scales (Robert & Guenther, 2006):

- Protecting the immediate health of building occupants;
- Protecting the health of the surrounding community;
- Protecting the health of the larger global community.

As presented in Figure 2, this "Triple Bottom Line for Health" defines the industry approach to sustainable building and operations and is the basis for the most relevant design tolls and guidance documents that have been developed for the purpose of making known healthcare organizations and your designers these challenges (Robert & Guenther, 2006). However, these assumptions increase its high complexity when consider the interests of the community and the population, which can also lead to failure of the same at its misapplication. In this sense the health industry should make an effort to take into account not only the technical needs of the hospital, the patients, the environment, but also the community at large (Figure 3).

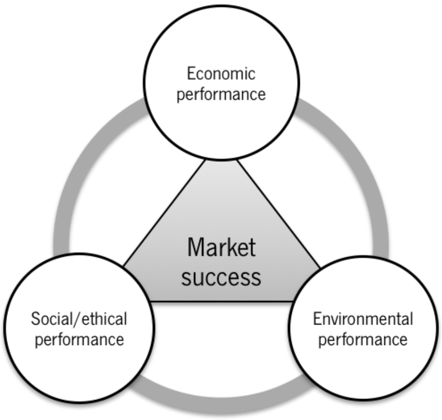

Figure 2. The Triple Bottom Line for Health (Roberts & Guenther, 2006)

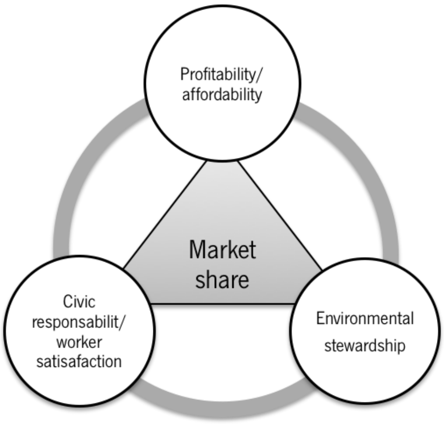

Figure 3. Applying the Triple Bottom Line Approach at the Community Level (Roberts & Guenther, 2006)

Healthcare is one of the most complex and rapidly changing industries. It is continually transformed by new technologies, technique, pharmaceuticals and delivery systems (Boone, 2012). Meanwhile, it is known that the use of different resources of the hospital who lives largely dependent on the: shape of building(s), construction and arrangement of the ground; climate in which it operates; relation of different design spaces; composition of circulation, waiting, service and operation areas; and functional program. In this concern, it is a fact that the hospital architecture incorporates a development project that has as main concerns the adequacy of technological advances in medicine, compliance with rules and regulations (that seek to ensure the quality of designed environments), the complexity and flexibility required for the project and the high cost of premises. This means that the designer often forgets or not gives the adequate importance to sustainable principles that this type of project should follow (Shaw et al, 2010). Consequently the construction of this type of buildings needs to incorporate this evolution and the spaces design can be the way to improve healthcare. The architectural design of the space, its organization, operation and configuration, allows these buildings to respond and adapt positively to the needs for which they are designed. At an early stage, a good investment in their flexible design reduces the need for further improvements (Johnson, 2010).

Analysing the indicators and parameters of the Building Sustainability Assessment (BSA) tools, specifically oriented to hospital buildings, it is possible to assess how important is the use of these methodologies in the architecture design phase to promote the existence of more sustainable buildings in the future. Many of these parameters are easily answered through the spatial and volumetric organization of indoor and outdoor spaces (Castro, et al. 2013). Therefore it is important to encourage the architects to incorporate these concerns in their projects, avoiding solving future problems resulting from the addition of equipment or other solutions that increase energy consumption, water or other resources, even human. Most times, sustainability assessments are used to comparatively classify the buildings. Nevertheless it is of increasingly importance that such methods are regarded as ordinary work tools in all project phases.

2 BUILDING SUSTAINABLE ASSESSMENT TOOLS

2.1 *The patient well being*

The hospital project contains different aspects from the most common projects of residential buildings, offices or services. In common buildings, sometimes the user and the client are the same and when they are not, setting the requirements is not difficult since they are common to most inhabitants. In the case of hospital buildings this is not the reality and the project team is usually hired for the purpose of designing a building that includes different spaces and different users, such as doctors, nurses, patients, visitors, cleaning staff, administrators, and others (Castro, et al., 2012). In this sense it is important to combine different spatial needs, which are always subject to constant changes throughout its period of use due to new features, innovations, needs expansion and new treatment methods (Figueiredo, 2008).

With the evolution of such buildings, it seems that the patient is increasingly occupying a central place of every concern and attention. Thus there should be a paradigm shift in the way these buildings are designed and the patient should be considered as the final customer of these structures (Figure 4).

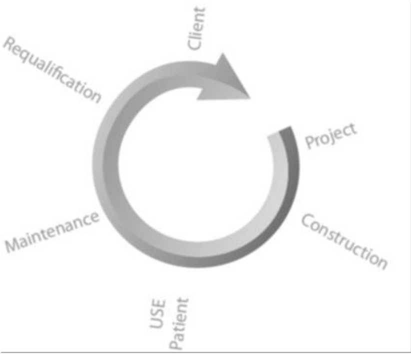

Figure 4. Life cycle of hospital buildings (Figueiredo, 2008)

One of the researchers that developed an important work related with human needs is Abraham Maslow, which grouped, in 1987, all human needs into a hierarchy: physiological; safety; social; esteem; and self-actualization. In this concern, the Institute of Medicine’s (IOM), defined, in 2001, its priorities based on the Maslow’s hierarchy, declaring that healthcare must be: safe; effective; timely; efficient; equitable; and patient centered (Clark & Malone, 2006).

2.2 *The contribution of space design to the sustainability of hospital buildings*

In Portugal, during 2008, the Ministry of Health developed a document that lists the recommendations and technical specifications for the hospital buildings, where there are recommendations for several issues, such as architecture, facilities and equipment for water supply and drainage, electrical and mechanical systems, centralized technical management, outdoor spaces, integrated management of solid waste, maintenance, etc. Together with this document, there are other regulations that specify the requirements of each specific space at the level of lighting, indoor air quality, temperature and ventilation. Nevertheless, in which regards to the sustainable management of the hospitals there is not any document with the force of law or recommendation.

In 2012, the Regional Health Administration of the Algarve summarized, in a manual, the good practices in sustainability health sector, which are divided into four main topics: Air quality and energy efficiency; Quality and availability of water; Resources and waste; and Quality of life. This manual aims to encourage the implementation of best mitigation and rehabilitation practices in the 218 units of national healthcare and is a good initiative to attract the attention of decision makers involved in the regeneration of this type of buildings. Nevertheless the design quality of the space is in most cases superficially addressed, eventually giving more importance to the introduction or modification of equipment and building elements improvements that make up the building.

Summarily the sustainable design of hospital buildings will result in competitive advantage strategies, as well as better economic, environmental and social efficiency. Thus, grouping the principles advocated by several authors, the main principles that support the sustainable design and construction of this type of buildings are (Castro, et al., 2012):

- Improve the quality of patient care;

- Reduce the time of patient recovery;
- Improve operational efficiency and productivity;
- Create increased facilities for users and surrounding communities;
- Contribute to the satisfaction and consequent fixation of employees and the experience positive patient (system performance evaluation of the complex);
- Develop quality and safe indoor and outdoor environments;
- Reduce operational risks associated with the project
- Increase the lifetime of the building;
- Reduce construction, operating and maintenance costs;
- Educate the understanding for the need to use a sustainability certification, allowing it to assess the pros and cons of introducing these design practices.

Thinking about these concerns it is also important thinking about this buildings' life cycle that need to include even more concerns compared to other type of buildings (Figure 5).

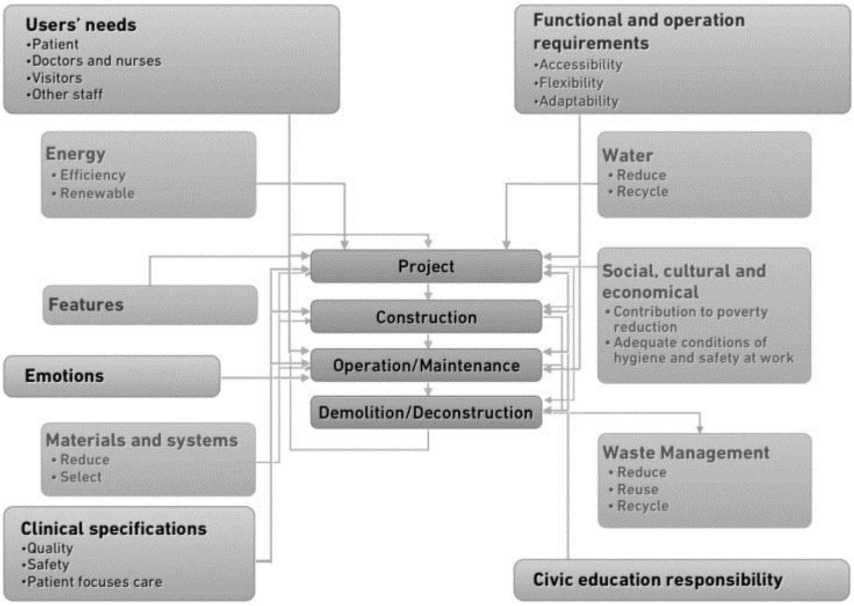

Figure 5. Life cycle of hospital buildings

3 BUILDING SUSTAINABLE ASSESSMENT TOOL FOR HOSPITAL BUILDINGS

3.1 *Existing tools*

All over the world there is a growing number of sustainability assessment tools developed for the building sector and oriented for new constructions, existing buildings and refurbishment/rehabilitation operations. Inside these three groups, most assessment tools are specifically oriented for different type of buildings. In the context of hospital buildings the most well known tools are: BREEEM Healthcare, LEED for Healthcare and Green Star – Healthcare (BREEAM, 2013; LEED, 2013; GBCA, 2013). In addition to these, DGNB is developing a specific methodology for hospitals that is not finished yet, and CASBEE has a system for *new construction* that includes the hospital buildings in the category of residential buildings. Nevertheless the CASBEE tool does not specifically address this type of buildings, but is one tool with different specifications for residential and no-residential buildings. For this reason, this study is focused on BREEAM Healthcare, LEED for Healthcare and Green Star - Healthcare.

The three abovementioned tools have a system of evaluation based in points that are divided over different categories, each of which is based in a series of evaluation parameters (Sauders, 2008). They have similar structure and similar list of criteria, which highlight the main aspects that initially started worrying humanity when we began to speak about the concept of sustainable development: Energy; Water; Materials; Pollution; and waste (Figure 6).

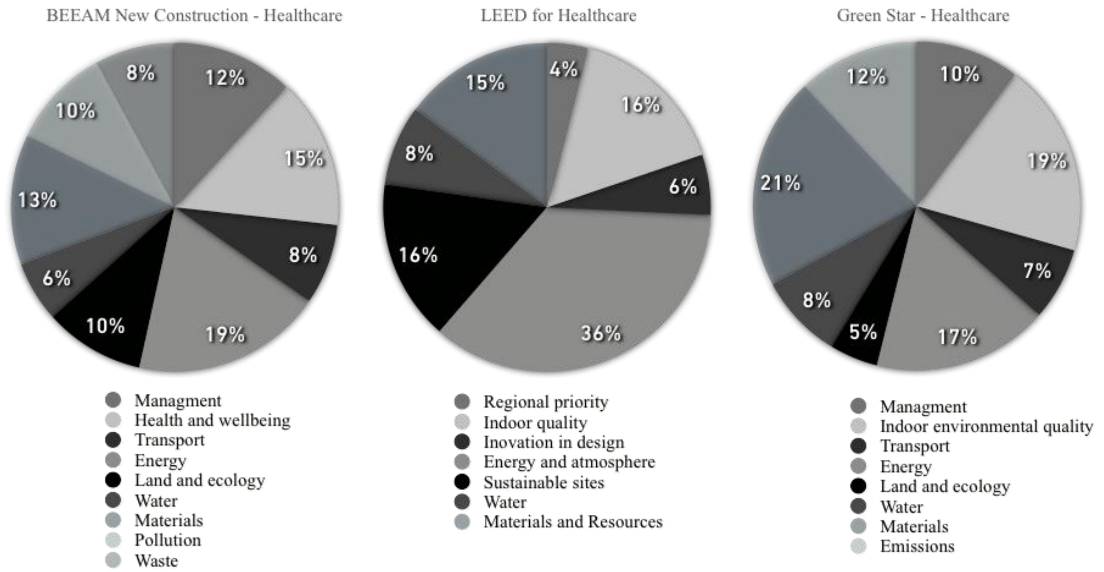

Figure 6. Criteria of the three most well known tools for healthcare

These criteria are absolutely important, but they are too much focused on environmental issues. At the moment we need to think about more parameters and more human requirements. These tools need to be more balanced on the level of the three pillars of sustainable development, namely: Environmental; Social; and Economical. Being aware of this, these tools do not consider the aspects of major importance to building designers, that are the functionality and operationally of space and the human requirements. In this scenario they are not generally adopted, because they bring a language that is not the same used by most building designers. Analyzing the indicators of each tool it is possible to conclude that there is no sustainability categories directly related with space design quality. Nevertheless there are some sustainability parameters that are indirectly related with that ao the category *Innovation in Design* (that allows getting an extra score in all tools) allows correcting a worst performance in other sustainability categories. Credits for innovative performance are awarded for comprehensive strategies, which demonstrate quantifiable sustainability benefits not specifically addressed by other sustainability categories. Table 1 presents the sustainability parameters of the abovementioned tools that are directly influenced by the indoor and outdoor spaces design quality.

Table 1. Sustainability parameters that are directly influenced by the spaces' design quality

Category	Parameters	Tools		
		BREEAM New Construction - Healthcare	LEED for Healthcare	Green Star Healthcare
Sustainable Sites	Light Pollution Reduction		x	
	Connection to the Natural World - Places of Respite		x	
	Connection to the Natural World - Direct Exterior Access for Patients		x	
Health &Wellbeing	Day lighting	x	x	x
	View Out	x	x	x
	Potential for Natural Ventilation	x		x
	Outdoor Space	x		x
	Arts in Health	x		
	Minimum Indoor Air Quality Performance		x	
Energy	Optimize Energy Performance		x	
	Lighting zoning			x
	Car park ventilation			x

Table 1 (cont.). Sustainability parameters that are directly influenced by the spaces' design quality

Category	Parameters	Tools		
		BREEAM New Construction - Healthcare	LEED for Healthcare	Green Star Healthcare
Transport	Proximity to amenities	x		
	Pedestrian and Cyclist Facilities	x	x	x
	Maximum Car Parking Capacity	x		x
	Deliveries and Manoeuvring	x		
	Community Mass-transports			x
	Transport design and planning			x
Materials and Resources	Compactor / Baler	x		
	Storage and Collection of Recyclables		x	
	Resource Use - Design for Flexibility		x	
Land Use & Ecology	Reuse of Land	x		x
	Contaminated Land	x		x
	Mitigating ecological impact	x		x
Innovation in Design	Innovation	x		x
	Integrative Project Planning and Design		x	
	Innovation in Design: Specific Title		x	
	Integrative Project Planning and Design		x	

These concerns in an integrated assessment tool to evaluate the sustainability of hospital buildings. The proposal is to divide criteria in three dimensions (environmental, social and functional, and economical) and incorporate the indoor and outdoor spaces design quality especially in the Sociocultural and functional quality category. Putting the patient at the center of concerns, some of the criteria that we proposed to integrate and research are expressed in the Figure 7.

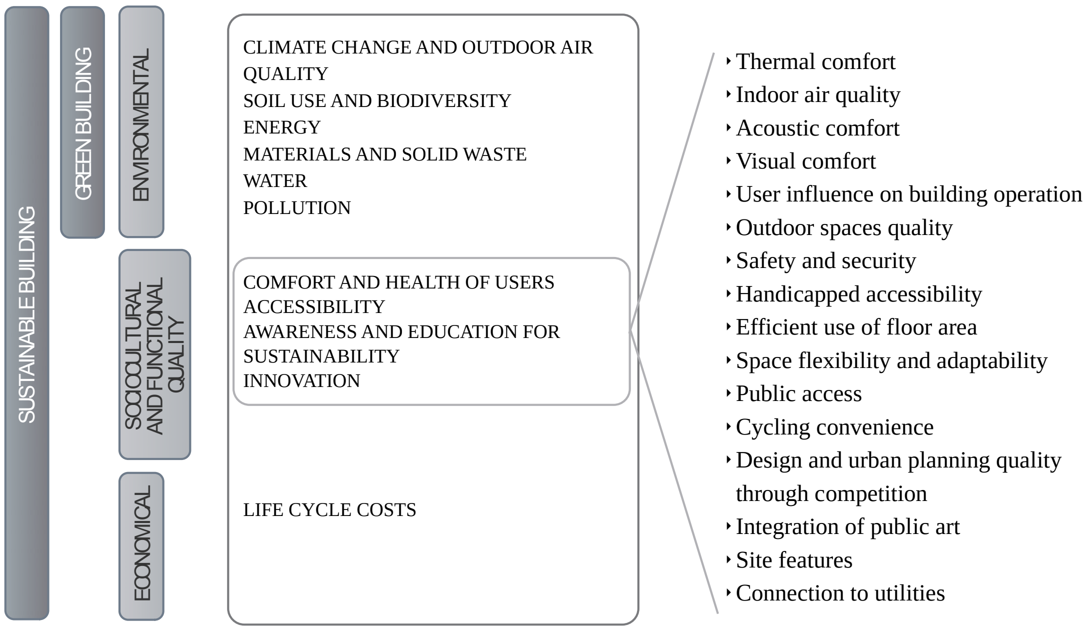

Figure 7. Proposal for structure of hospital buildings BSA tool

4 CONCLUSIONS

It is relevant to promote and discuss the importance of the space organization to the sustainable construction and the influence of the architecture (and not only the building systems) in the BSA tools. It is also important that each designer involved in the development and construction of hospital buildings is able to quickly identify a set of parameters that have the greatest influence in the whole building sustainability. All in all these tools must be bivalent, since they must impose the concerns with sustainable construction but also integrate the requirements of each building and each project area, linking priorities and facilitating the widespread integration of several concerns in the different design projects. This is one aspect that can promote the use of these tools by all project teams involved in the construction of this building typology, as well as their use in different phases of buildings life cycle.

4.1 *Acknowledgement*

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The Development of Building materials Embodied Greenhouse gases Assessment System (SUSB-BEGAS) for Supporting the Green Building Certification System (G-SEED) in Korea

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ABSTRACT: This study aims to develop Building materials Embodied Greenhouse gases Assessment System (SUSB-BEGAS) for supporting green building certification system (G-SEED) in Korea. For this purpose, main building materials which met the cut-off level of ISO 14040 were drew based on the bill of quantities and selected the targets of evaluation for this study by reflecting the opinions of technical committee of green building certification standard. In addition, the Korea National LCI DB, LCI DB of Korea Ministry of Land, Infrastructure and Transport, and carbon footprint labelling certificate of Korea Environmental Industry & Technology Institute were adopted as the database of this study for reflecting the social features of Korea. As a result, Building materials Embodied Greenhouse gases Assessment System (SUSB-BEGAS) at the web environment applicable have been developed at the green building certification system (G-SEED).

1 INSTRUCTION

As the global environment problem attributable to greenhouse gas has emerged as the main issue of the international society, efforts to reduce greenhouse gas have been accelerated on the construction industry, the main industry generating greenhouse gas. As a part of this, environmentally advanced countries such as USA, UK and Japan have competitively created and complemented the items of evaluating the greenhouse gas emission throughout the life cycle of the building within the environment friendly building certification system (Finnveden et al. 2009, Li.2006).

In this regard, Korea has gradually expanded and executed the building energy consumption total emission system, building greenhouse gas and energy goal management system according to international agenda. However, this is the greenhouse reduction policy focusing on the energy consumed in the operation process of building and has a limit that it fails to reflect the greenhouse gas emission of building materials which takes about 32% of life cycle greenhouse gas emission of building (Ko et al. 2007, Lee. 2010, Roh & Tae. 2011). There is a drive in green building certification system(Green Standard for Energy and Environmental Design, hereinafter G-SEED) to create items of greenhouse emission evaluation for the building materials in order to consider environmental loads of various cycles(material production, construction, operation, maintenance, dismantle disposal) that building embodies. However, there are no sufficient technology to evaluate the greenhouse gas emission of building materials and studies that can connect this to G-SEED (Tae & Shin. 2009).

This study aims to develop Building materials Embodied Greenhouse gases Assessment System (hereinafter SUSB-BEGAS) for supporting G-SEED in Korea.

For this purpose, the environment-friendly building certification system mainly used at global were analyzed to explore items of greenhouse gas emission evaluation of building materials. In addition, by drawing the main building materials focusing on the greenhouse gas emission that meets the cut-off level of ISO 14040 based on the bills of quantities of actual apartment houses and office building and reflecting the opinions of technical committee of green building certification standard, we selected the targets of evaluation for this study. In addition, the Korea National LCI DB, national DB of building material environmental feature information, and carbon-footprint labelling certificate of Korea Environmental Industry & Technology Institutewere adopted as the database of this study for reflecting the social features of Korea. Based on the database constructed as above, web-based SUSB-BEGAS have been developedat the G-SEED.

2 CONSIDERATION OF BUILDING MATERIAL GREENHOUSE GAS ASSESSMENT

2.1 *Overview*

With the most commonly used environment-friendly building certification systems at home and abroad such as LEED (USA), BREEAM (UK), CASBEE (Japan) and Korean G-SEED (before amendment), items of greenhouse gas evaluation of building materials applicable at each system were compared and analyzed as shown in the Table 1.

2.2 *LEED v4-draft*

Among the evaluation items of USA LEED, evaluation items of life cycle greenhouse gas emission of building material was included in Materials and Resources. As it was newly created (LEED v4-draft, 2012) as the No. 1 evaluation item (M.R. Credit 1. Building Life-Cycle Impact Reduction) in the material and resource part with the type of extra point (LEED v3, 2009) from existing innovation design item, it was analyzed to add weight to the influence of greenhouse gas emission evaluation of the building materials in the certification system. It could be evaluated through ‘Option 4. Whole-Building Life-Cycle Assessment’ of M.R. Credit 1, and found out that up to 3 point score would be given for the environmental load reduction over 10 % compared to the standard building through life cycle evaluation program of building materials designated by LEED including Athena Eco Calculator for Assemblies, BEES.

Table 1. Comparison and analysis of environment-friendly building certification system

Classification	LEED v4-draft	BREEAM 2009	CASBEE 2010	G-SEED (before amendment)
Country	USA	UK	Japan	Korea
Announcement	2012	2011	2010	2011
Target	New buildings	New buildings	New buildings	All buildings
By	USGBC	BRE	Japanese Ministry of Land, Infrastructure, Transport and Tourism	Korea Ministry of Environment& Korea Ministry of Land, Infrastructure and Transport
Evaluation item classification system	Sector(7) Evaluation item(56)	Sector(10) Evaluation item(50)	Sector(2) Evaluation item(55)	Sector(9) Evaluation item(52)
Building materialLCA evaluation item	Materials and Resources	Materials	Resources and Materials	-
Environment impact evaluation item	GWP, ODP, AP, EP, POCP, ERS	7 in addition to AD, OD, HTox Water, HTox Air, POCP, Ecotox	$LCCO_2$	-
Building materialLCA evaluation method	LEED LCA Credit Calculator evaluation based on EcoCalculator	Green guide to specification evaluation based on green guide	Self-evaluation through spread sheet(Excel)	-
Building material LCA score	Up to 3 points	Up to 5 points	BEE index	-

2.3 *BREEAM*

In UK BREEAM, the greenhouse gas emission evaluation items of building materials corresponds to Materials Part and the life cycle evaluation of building is conducted through 'Mat.1 : Life Cycle Impacts (Major Building Elements)' certification items. Evaluation targets are the main members of building types and separated into method of applying green guide database, constructed at BRE, and that of utilizing the life cycle assessment program designated at BRE. Green guide database evaluation method was analyzed to give up to 5 points after carrying out rating through summary rating per 290 major building elements. On the other hand, the evaluation method of utilizing life cycle assessment program was analyzed to give up to 5 points if presenting to the examiner the documentary evidence proving confirmation of environmental load reduction of materials compared to standard building and using Envest2, Eco-Quantum.

2.4 *CASBEE*

Japan CASBEE is the evaluation system that introduces the index concept by separating the building environment efficiency (BEE). It is separated into the numerator of BEE, Q (Quality : building quality performance) and denominator L(Loadings : external environmental load of building). Greenhouse gas emission of building materials is evaluated at L2(resource and material) and life cycle CO_2 emission of building is evaluated through 'L2.2.2 Continuing Use of Existing Structural Frame etc'. Materials for evaluation are 5 main materials including concrete, blast furnace cement concrete, steel frame, rebar and woods. It was analyzed to evaluate the life cycle CO emission of the building through spread sheet (Excel) provided and material input quantity per unit area, CO_2 database.

2.5 *G-SEED (Before Amendment)*

Korean G-SEED (before amendment) is classified into 9 categories such as land use, transportation, energy, material, resource, water resource, prevention of environmental pollution, maintenance, ecosystem and interior environment according to feature of building. Total points are calculated with weighted value and achievement rate for each item of 50 items, but the evaluation items of greenhouse gas emission of building materials was not created.

3 SELECTION OF EVALUATION TARGETS OF SUSB-BEGAS

3.1 *Overview*

To deduce main building materials emitting greenhouse gas to be applied for target of evaluation at SUSB-BEGAS, the bills of quantities of many apartment houses and office buildings constructed in Korea were analyzed, and the main building materials of greenhouse gas emission were deduced according to cut-off level specified in ISO 14040. In addition, by reflecting the opinions of technical committee of green building certification standard, a total of 4 elevation targets were selected including ready-mixed concrete, rebar, steel frame and cement.

3.2 *Deduction of Main building materials*

To deduce the main building materials emitting greenhouse gas among the building materials used for building, we evaluated the greenhouse gas emission of building materials used for construction works based on the bills of quantities of many apartment buildings and office buildings, and identified the building materials with over 95% accumulated greenhouse gas emission according to the cut-off level of ISO 14040(Lee et al. 2009, Shin et al 2011). At this time, top 6 greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) including CO_2 emission were set as the gases for evaluation and converted to carbon dioxide equivalent (CO_{2eq}) by reflecting Global Warming Potential (GWP) of IPCC. As a result, 7 building materials such as ready-mixed concrete, rebar, steel frame, paint, glass, concrete product and insulators were found to take over 95% of greenhouse gas emission in the apartment houses and office buildings. In this regard, this study deduced above 7 building materials and a total of 7 main building materials including cement which had relatively high basic unit of greenhouse gas emission, and in case of RC structure, 6 building materials except steel frame were selected as the main greenhouse gas emission materials.

3.3 *Selection of building materials for Evaluation*

To review suitability and to determine applicability of main 7 building materials emitting greenhouse gas including ready-mixed concrete, rebar, steel frame, paint, glass, concrete products and insulation materials deduced above, we have reviewed and consulted with the material and resource subcommittee of technical committee of green building certification standard. In addition, as shown in table 2 above, in consideration of the efficiency and reality of building drawings calculated according to evaluation period of G-SEED per project stage (project approval stage: preliminary certification, completion stage: certification), this study restricted the target building materials for evaluation into 4 types such as ready-mixed concrete, rebar, steel frame (only if SRC structure or S structure), and cement (Nam et al. 2011).

Table 2. Evaluation period of G-SEED per project stage

Construction Process	Basic Design	Deliberation	Project Approval	Detailed Drawing	Starting and Construction	Completion
G-SEED Certification Period	-	-	Preliminary certification	-	-	Certification
Drawings	Layout, Plane	-	Construction drawing	Bills of quantities	Work log	Details of completion

4 DEVELOPMENT OF SUSB-BEGAS

4.1 *Overview*

This study developed web-based SUSB-BEGAS reflecting the G-SEED based on the database and evaluation technique established above.

4.2 *Targets and Scope of Evaluation*

Evaluation targets of SUSB-BEGAS are set to 4 types of building materials (read-mix concrete, cement, bar steel, sectional steel for reinforced concrete) which could be easily applied at the evaluation stages (preliminary certification, certification) of Korean G-SEED. Evaluation scope of greenhouse gas was set to 6 types of greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) emission set at IPCC, and expressed as carbon dioxide equivalent (CO_{2eq}) in consideration of GWP for each gas.

4.3 *Basic Unit Database of Greenhouse Gas Emission*

Main database of SUSB-BEGAS were Korea national LCI DB, constructed by the Korea Ministry of Knowledge and Economy, and Korea Ministry of Environment in reflection of the environmental features of Korea, national DB on environmental information of building materials constructed by Ministry of Land, Infrastructure and Transport in greenhouse gas basic unit of general building materials. On the other hand, in case of G-SEED certification, when the information on building material used to the building is disclosed, if carbon footprint labelling product by Korea Environmental Industry & Technology Institute was actually used in the building, it was constructed to apply greenhouse gas won unit of the carbon footprint labelling. Table 3 shows the LCI Database of ready-mixed concrete, rebar, sectional bar and cement.

Table 3. Status of LCI database application per building materials

Classification	Name	Basic unit	Unit	DB source	Remarks
Ready-mixed concrete	Ready-mixed concrete	346.000	kg-CO_{2eq}/m^3	Korea National LCI DB	Applicable for certification
	Ready-mixed concrete [Spec.:25-24-150]	835.000	kg-CO_{2eq}/m^3	Carbon footprint labelling	
	Ready-mixed concrete [Spec.:25-21-150]	201.000	kg-CO_{2eq}/m^3	Carbon footprint labelling	
	Pre-cast concrete [MPS build-up girder]	189.000	kg-CO_{2eq}/m^3	Carbonfootprint labelling	
Rebar	Steel making at electric furnace -Rebar	0.760	kg-CO_{2eq}/kg	Korea National LCI DB	
Sectional steel	H sectional steel	0.397	kg-CO_{2eq}/kg	LCI DB of Korea MLIT	
Cement	Cement	0.944	kg-CO_{2eq}/kg	Korea National LCI DB	

4.4 *Configuration of SUSB-BEGAS*

The main function of SUSB-BEGAS developed at this study is the evaluation of greenhouse gas, and was made up of 2 simple screens of information input and evaluation results for easy evaluation of greenhouse gas emission of building materials. It can be evaluated by separating into preliminary certification and certification according to the progress of G-SEED. Figure 1 shows the configuration of SUSB-BEGAS developed by this study.

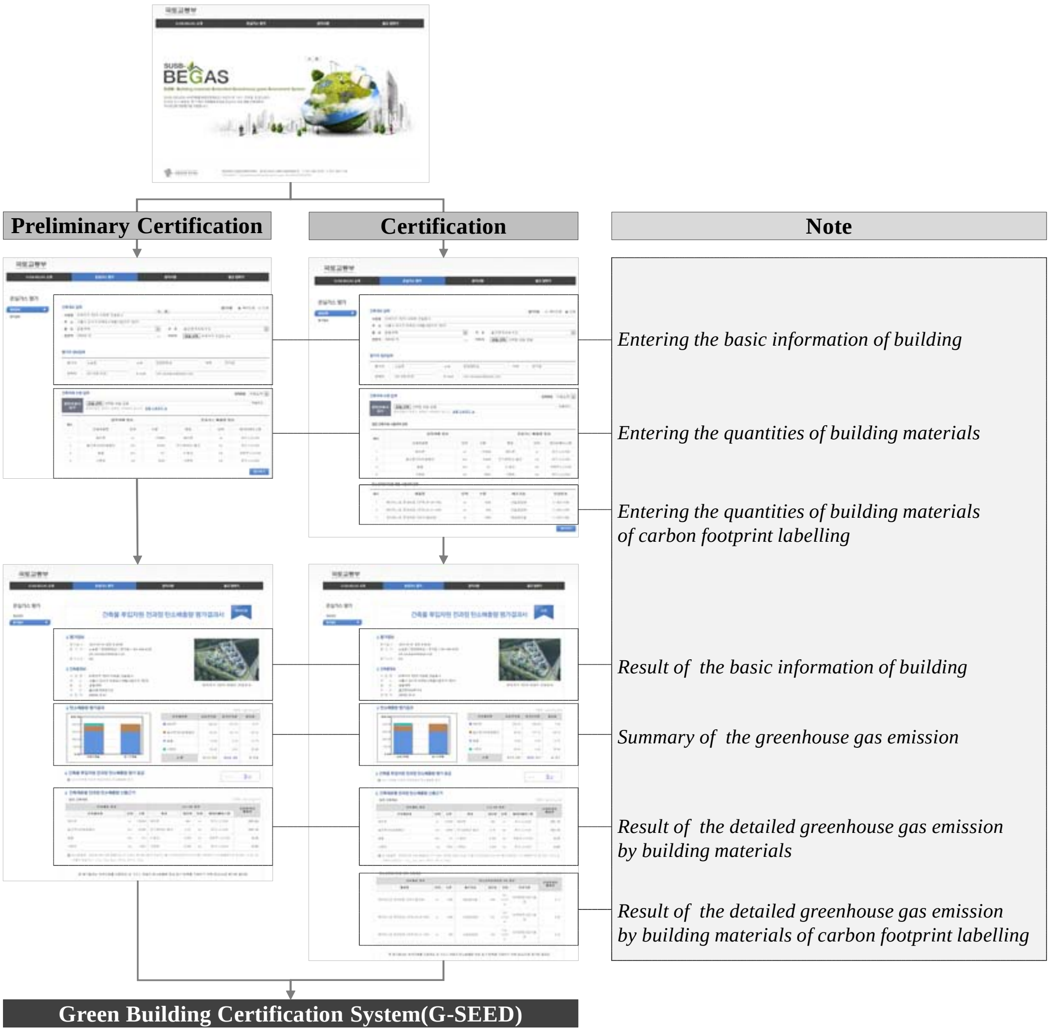

Figure 1. SUSB-BEGAS configuration

Preliminary certification is moved to the evaluation results by entering the basic information of building and quantities of building materials and through the evaluation button. Evaluation results of preliminary certification consist of basic information of building (evaluation information, building information), evaluation results of greenhouse gas emission, life cycle greenhouse gas emission evaluation rating, and grounds for calculation of life cycle greenhouse gas emission for each material. It can be printed or downloaded as Excel and evaluated as the evaluation results of life cycle greenhouse emission of building.

Certification is conducted in the same form as preliminary certification, and can be entered and applied for the building materials acquiring carbon footprint labelling carried out by Korea Environmental Industry & Technology Institute along with application for general building materials. Evaluation result is structured same as the preliminary certification, but the acquisition of carbon footprint labelling and evaluation results of building materials are additionally displayed on the bottom part so that it can be printed or downloaded as Excel, used as the life cycle greenhouse gas emission evaluation results of the building materials.

5 CONCLUSION

This study aims to develop SUSB-BEGAS for supporting G-SEED and obtained the following conclusions.

1. Compared and analyzed the greenhouse gas evaluation items of building materials applied in each environment-friendly certification systems on the main environment-friendly certification system of LEED, BREEAM, CASBEE and Korean G-SEED (before amendment).
2. Analyzed the bills of quantities of building, deduced the main building materials emitting the greenhouse gas, and selected the evaluation targets of ready-mixed concrete, rebar, steel frame and cement by reflecting the opinions of technical committee of green building certification standard.
3. Developed the web-based SUSB-BEGAS which could be easily reflected in G-SEED with 4 building materials shown above.

6 ACKNOWLEDGEMENT

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Can sustainability rating systems fairly assess construction solutions under assessment?

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ABSTRACT: There are several sustainability assessment schemes developed throughout the world. Each has its own aim, scope and scale, but frequently the same aspects are addressed. Methodologies have been mostly developed locally, meaning that they are specific for a country, legislation, standards or even for most common construction solution used in that area. This might mean that if applied to different areas, legislations, standards or even different construction solutions the assessment results can be biased, not showing the real sustainable potential of that building. Bearing in mind, this paper addresses how existent sustainability assessment schemes evaluate steel as construction solution.
In order to achieve this aim, first a comparison between the methodologies is presented. Only then, the way that steel properties' are evaluated is analysed. From the assessment it was verified that steel solutions can achieve good results. However none of the addressed methodologies consider all the identified steel sustainability potential.

1 INTRODUCTION

With the construction and real estate evolution some materials have emerged. Steel, although not a new material, is getting more attention, especially because of its recyclability (Living Steel, 2010, Gervásio, 2008). Steel buildings have also been target of studies advocating their sustainable benefits, proclaiming their adaptability and flexibility, since parts can be easily added or taken off or demounted; their low operation and effective embodied energy (Santos et al., 2010, Gervásio et al., 2010); foundations can be extracted from the site and also can be lightweight; high ratio strength- weight (Landolfo et al., 2004); fabric/offsite manufacture, allowing just in time deliverables, better safety and health conditions for workers, higher product quality and quicker production and building construction; bigger life span, accomplished by gathering the other characteristics (Jaillon et al., 2009, Goodier and Gibb, 2007, Blismas et al., 2006); multi-cycling products, as steel can be continuously recycled without losing its quality and properties (Living Steel, 2010, Gervásio, 2008); recyclable and re-usable; great thermal mass performance, etc.

Several case-studies have been published assessing buildings sustainability, environmental or even energy performance; others, had reviewed and compare sustainability assessment systems as e.g. by Forsberg and Malmborg (Forsberg and von Malmborg, 2004), Haapio and Viitaniemi (Haapio and Viitaniemi, 2008), or Ding (Ding, 2008). However neither of them has specifically focused their adaptability to the different typologies of building construction solutions, such as steel, concrete or timber. Therefore, the paper aims to offer information to compare different sustainability assessment methods considering steel construction solutions, especially in early design phases.

2 SUSTAINABILITY ASSESSMENT TOOLS

Pre-design and design phases are regarded as crucial to the sustainability performance of a building throughout its life-cycle. Unfortunately, the supportive decision-making methodology is poorly developed for these phases.

There are different perspective to assess a building's sustainability (Bragança et al., 2007). Sustainability assessment methodologies can be oriented to different scales of analysis: building material, building product, construction element, independent zone, building and the neighbourhood, or even to different life-cycle phase.

This paper will focus in the comparison of BREEAM (BREEAM, 2011), LEED (LEED®, 2010), ATHENA (ATHENA®, 2008), SB Tool (iiSBE, 2009, Bragança and Mateus, 2009, Mateus and Bragança, 2011), Eco-Quantum (Eco-Quantum) and CASBEE (IBEC, 2009), taking into account the following criteria:

- Relevance: Has the methodology a holistic approach?
- Coverage: Do the methods cover all sustainability dimensions? Which are the sustainability indicators focused by the methodology?
- Applicability: which building typologies can be assessed? Which life-cycle phases are included in the assessment?
- Adaptability: Are the methodologies easily applicable to steel-framed buildings? Do they truly acknowledge the steel sustainability potential?

2.1 *Relevance*

Early design phases are crucial for the buildings life cycle sustainability (Hanna and Skiffington, 2010, Bunz et al., 2006). Holistic and systemic approaches are hence most effective when used in these phases. According to Ding (Ding, 2008) it is important to separate project design and project assessment, as the assessment process is usually carried out when the project's design is almost concluded. In this way, sustainability assessment methods to be truly useful must be introduced as early as possible, allowing interrelation between designing and assessing teams. Analysing the most well-known and used methodologies it is possible to divide them depending on their scope, into three main groups (Trusty, 2000, Bragança et al., 2010):

- Systems to manage overall building performance (Performance Based Design);
- Life-cycle assessment systems with additions of social, cultural and economic issues;
- Sustainable building rating and certification systems.

From the subject methodologies, Eco-Quantum and ATHENA represent life-cycle assessment systems, while BREEAM, LEED, SBTool, CASBEE and DGNB correspond to Sustainable building rating and certification systems.

2.2 *Coverage*

Sustainability assessment is nowadays widely mentioned; however it is most of the times just regarded as an environmental issue and not giving so much attention to the functional, social and economic performance. Weighting is inherent to all systems and, according to Lee (Lee et al., 2002), it is the heart of all assessment systems, as it is responsible for establishing the overall performance score. However, its establishment is not unanimous there is not yet a consensus-base method to guide the weightings assignment (Ding, 2008).

Figure 1 shows schematically the weighting factors given to sets of sustainability indicators in each of the methodologies assessed. ATHENA and Eco-Quantum address environmental aspects only and interim weighting factors are not publicly available, so they were also out of the plot drawing. Regarding CASBEE, it is not possible to determine the weight of the two main indicators groups to the final score – the "building environmental quality (Q)" and the "building environmental load (LR)" – since they rely on the interim scores of each addressed category; still, their contribution is shown in Table 1 (IBEC, 2008).

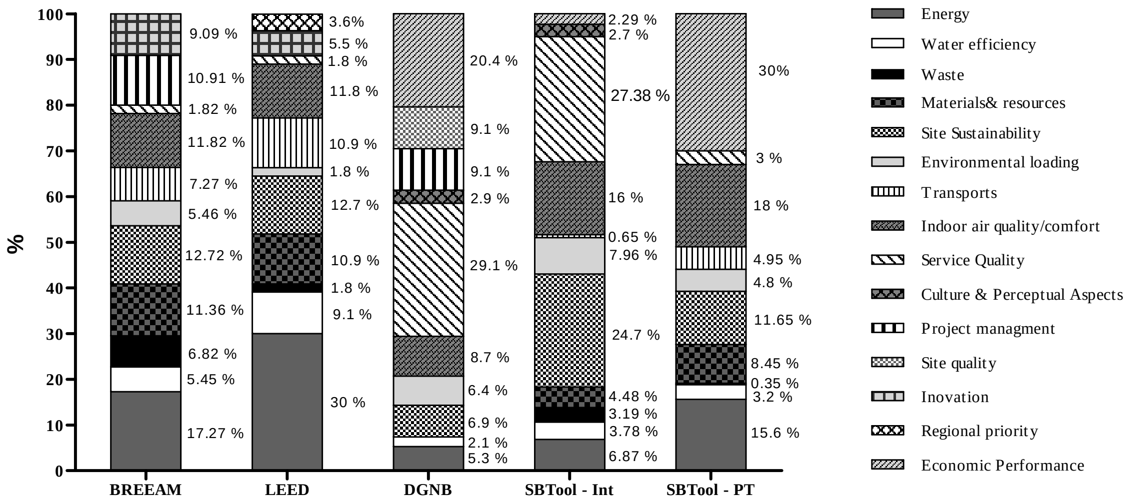

Figure 1. Sustainability methodologies weights distribution

Table 1. CASBEE weighting factors (IBEC, 2008)

building environmental quality			building environmental load		
Q1	Indoor environment	0.4	LR1	Energy	0.4
Q2	Quality of Service	0.3	LR2	Resources & Materials	0.3
Q3	Outdoor Environment on Site	0.3	LR3	Off-site Environment	0.3

From all the assessing methodologies, just SBTool and DGNB consider the three main sustainable dimensions: environment, social and economy. Neither LEED nor BREEAM consider cost issues, instead both systems focus on the eco-friendly aspects such as energy, water, and indoor environment. Cultural and/or aesthetic aspects – that are normally added to the social field – are just considered in SBTool (International 2011 version) and DGNB. Project Management is just regarded in BREEAM and DGNB, accounting about 10% to the final score in the first two approaches. In the social field, all the rating systems assessed consider indoor comfort and health aspects, though service quality is barely accounted in BREEAM, LEED and SBTool^{PT} (version 2009/2 - homes) (Bragança and Mateus, 2009, Mateus and Bragança, 2011). On the contrary, SBTool International and DGNB give an important position to service quality. Concerning ecological aspects, all the methodologies concentrate a great effort in this field. Aspects related to energy and site sustainability have the highest percentage in the ecologic weight. A more detailed comparison, at the indicators level, is presented in Table 2.

Table 2. Main issues accounted in the sustainability assessment methodologies

	BREEAM	LEED	SBTool	SBTool^{PT}	DGNB	ATHENA	Eco-Quantum	CASBEE
Energy								
Low CO_2 emissions	x		x		x			
Renewable energy		x	x	x	x	x	x	x
Natural/local energy		x						x
Efficiency	x	x		x	x			x
Electrical Demand	x	x	x		x			x
Low or zero carbon	x		x		x			
energy monitoring	x	x					x	x
Water Efficiency								
Re-use/recycling	x	x	x	x				x
Water consumption	x	x	x	x	x			x
Water monitoring	x							
Leak detention	x							
Waste								
Construction waste	x	x	x					
Non-hazardous waste	x		x				x	
Hazardous waste	x		x	x			x	

	BREEAM	LEED	SBTool	$SBTool^{PT}$	DGNB	ATHENA	Eco-Quantum	CASBEE
Liquid effluents			x		x			
Materials and Resources								
Materials reuse	x	x	x	x	x			x
Recycled content		x		x				x
Renewable sources		x	x			x	x	x
Responsible sourcing	x	x		x	x			x
Robustness	x				x			
Ease of disassembly, re-use or recycling			x		x			
Site Sustainability								
Site Selection	x	x	x	x	(x)			
Site development		x	x					
Land use			x	x	x		x	
Heat Island effect		x		x	x			x
Noise control	x			x	x			x
Development of community		x			(x)			
Stormwater design	x	x						
Local ecology/ biodiversity	x		x	x				x
Regional impacts	x		x		x			x
Access to daylight			x					x
Influence in other constructions			x					x
Light pollution	x	x	x					x
Environmental loading								
Atmospheric emissions	x	x	x	x	x	x	x	x
LCA	x		x	x	x	x	x	x
Transports								
Public transports	x	x	x	x	(x)			
Cycling accessibility	x	x			x			
Indoor air quality								
Thermal comfort	x	x	x	x	x			x
Visual comfort	x	x	x	x	x			x
Acoustics	x		x	x	x			x
Hygiene	x	x	x	x	x			x
Ventilation	x	x	x	x				x
Water quality	x							
Service Quality								
Flexibility/adaptability			x		x			x
Disable persons access					x			
Safety and security	x		x		x			
Earthquake resistance								x
Maintenance management			x		x			x
Spatial efficiency			x		x			x
User controllability			x					x
Functionality			x					x
Fire prevention					x			
Cultural & Aesthetics								
Culture & heritage			x					
Aesthetic quality			x		x			
Project Management								
Planning	x				x			
Construction phase					x			
Stakeholders participation	x				x			
Site impacts	x				x			

	BREEAM	LEED	SBTool	SBTool^{PT}	DGNB	ATHENA	Eco-Quantum	CASBEE
			Economic issues					
Construction Costs			x		x			
LCC			x		x		x	
Value Stability					x			
Local economy			x					

2.3 *Adaptability*

Sustainability assessment methodologies can be used in different life cycle phases (Table 3) and also in several buildings typologies or even building products (
Table 4). Bragança et al (Bragança and Koukkari, 2007) focused the importance of considering sustainability through the building life-cycle with an integrated design approach. The ATHENA methodologies classification states that Level 1 methodologies (performance-based) are more likely to address products comparisons and supply information, while Level 2 (LCA-based) and Level 3 (Rating and Certification Systems) systems mainly the building as a whole (Trusty, 2000).

There are different building typologies and all the systems assessed, with the exception of Eco-Quantum, are able to analyse more than one. Methodologies like BREEAM, LEED, CASBEE or DGNB have different versions for the different buildings types and also for its stage (new construction, existing building or refurbishment). CASBEE has under development a tool version to assist planning/pre-design of the project (IBEC, 2009).

Table 3. Assessed buildings typologies

	BREEAM	LEED	SBTool	ATHENA	Eco-Quantum	CASBEE	DGNB
Pre-Design						*	
Existing buildings	x	x		x	x	x	
New buildings	x	x	x	x	x	x	x
Refurbishment	x	x	x	x		x	
Building product					x	x	
Residential building (multi story)	x	x	x	x		x	x
Homes (single family)	x	x	x	x	x	x	x
Offices	x	x	x	x[1]		x	x
Schools	x	x				x	x
Hospitals	x	x				x	
Retail	x	x	x			x	x
Industrial	x	x					x
Prisons	x						

* under development | 1 – and other types of buildings but without specification

Table 4. Life Cycle Phases considered

	BREEAM	LEED	SBTool	ATHENA	Eco-Quantum	CASBEE	DGNB
Project/design	x		x				x
Production	x	x	x	x			
Construction	x	x	x	x	x	x	x
Use/Operation	x	x	x		x	x	x
Maintenance	x	x	x	x	x	x	
Demolition		x	x	x	x		
Disposal	x	x		x	x		

All methodologies have different approaches to life-cycle phases. None of them is cable of addressing all phases, but BREEAM, LEED and SBTool present a better coverage. ATHENA, for example accounts for construction, demolition and disposal, but it does not consider the operation phase; BREEAM, although considers disposal does not includes demolition. SBTool addresses demolition, but not disposal. CASBEE only takes into account construction, operation and maintenance. Despite considering mainly the same phases, the approach to them may vary from system to system.

3 APPLICATIONS TO STEEL-FRAMED BUILDINGS

In order to examine the sustainability assessment methodologies potential within steel construction it is necessary to determine which of the issues included in their approach can be associated with steel buildings' technology and consider its potential towards sustainability.

LCA-based methods have an in-depth coverage of environmental impacts associated with design and building materials. ATHENA and Eco-Quantum approaches, although not directly related to steel construction, can easily promote it. One of steel construction's advantages is its recycled content rate or even the fact that iron is one of the most abundant materials on earth. Hence, by accounting the steel making process and the end-use solutions, these systems can certainly declare the environmental potential of this technology.

When taking a closer look to the steel main sustainable factors together with the assessment approaches and the main issues considered by them (following the categories presents in Figure 1) it is possible to identify its specific applicability.

For example, steel's off-site manufacture can contribute positively for achieving a great score in site sustainability, waste, project management or materials and resources categories. Steel just in time delivery and faster construction can lead to fewer impacts on the site and locality, as reducing location traffic congestion, contributing to more workable conditions in difficult urban sites. LEED's 'Development density and community connectivity' credit, SBTool's 'Impact of construction process on local residents and commercial facilities users' and 'Impact on private vehicles used by building population on peak load capacity of local road system' indicators, or CASBEE's 'Load on local infrastructure' item can address this benefits. Also, the less waste production reduces the need of outputting them from the site, leading to less energy spent in transportation. This issue can also be addressed in BREEAM's 'construction site impacts' credits. The use of steel also provides the opportunity for management systems that reduce site disturbance. This can be accounted in LEED, BREEAM, SBTool and DGNB "site development" aspects and also in BRREAM's "responsible construction practices" credits. Also for indicators related to site development or sustainability, steel properties as its lightweight, lighter and smaller foundations or flexibility, which enable difficult urban sites to be more readily exploited, can be regarded as positive contributions towards building's sustainability.

The lightweight steel solutions are a great benefit when, for example, re-developing contaminated sites, as these structures require less ground works. Moreover, large scale prefabrication using steel components can reduce disturbance of the polluted ground. These facts can be accounted in LEED 'Brownfield redevelopment', BREEAM's 'site selection', SBTool 'Use of previously contaminated land for development' and DGNB 'site location conditions' items. Lightweight solutions also contribute for reducing the amount of materials used and to less exploitation of natural resources; these facts are considered for instance, in CASBEE 'Reducing usage of materials'.

The most mentioned property of steel when talking about sustainability, is its recyclability and multicycling, which contribute both for reducing demolition or production waste and to improve the recycled content of the building. Among all the methodologies referred, LEED is the one that best addresses this important property of steel. It is dealt with in several items from the materials category, as 'Construction waste management', 'Recycled content' and 'Regional materials'. SBTool also considers this matter in 'use of virgin non-renewable materials' and in 'Easy of disassembly, re-use or recycling'; CASBEE acknowledges steel's recyclability by 'Use of recycled materials as structural frame materials' and DGNB by 'Ease of dismantling and recycling'.

Besides being easily recycled steel can also be easily re-used. Due to its bolted connections, steel structures can simply be detached from each other and demounted without generating dust, dirt and high noise levels. This re-usability turns steel structures into very flexible and adaptable structures, allowing them to be demounted in one place and re-mounted in another, even if the goal of the building is quite different from the first one. Steel is also very adaptable and flexible as it connects well with existing structures or façades in the site, allowing them to be included in the new building. This reduces materials usage and contributes, for example, to keep a location aesthetics and heritage. Re-use, flexibility and adaptability of steel structures can be addressed in the different methodologies in items as BREEAM's 'Materials life cycle impacts', LEED's two credits regarding building reuse and 'Material re-use' and SBTool's 'Degree of re-use of suitable existing structures where available'.

Regarding indoor air quality, service quality and functionality aspects, although not directly related to steel construction, as good results can also be achieved by other construction solutions, steel construction easily achieve great scores when being assessed by the above mentioned methodologies. For instance, indicators related to the indoor air conditions contain issues such as visual, thermal and acoustic comfort, which are related not only to the flexibility of steel structures but also the wide variety of materials that can be easily included in the structure during the building design; good thermal and acoustic insulation materials can be added and highly glazed areas have a great affinity with steel buildings. Service quality and functionality of steel buildings can be rewarded by its flexibility allowing a great spatial efficiency and suitability to desired function, by ensuring easy access to the structure components, facilitating maintenance operations. The fire prevention aspect assessed by DGNB also contributes to promote steel construction since it is a good fire delayer.

SBTool is the only approach accounting safety and health aspects during the construction phase. The off-site manufacture of steel also contributes to a more controllable and safer work period, reducing the workers' exposure to risks.

Finally, the faster construction period, the long life span, the easy maintenance operation without big material loses and the great performance regarding thermal needs, contribute to less expenses and hence to obtain a greater economic performance in SBTool and DGNB assessments.

4 CONCLUSIONS

The building's sustainability assessment is a wide field with too many variables and stakeholders involved. Although all efforts sustainability assessment methods have been developed without a standard an, even though different methodologies can include the same aspects, the approach to them might be very different between them. Therefore International standards organizations as ISO and CEN have been struggling to publish standards that will certainly aid sustainability assessment. However, not all the aspects and procedures are been followed by the existing methodologies. It is hence essential to introduce standardisation recommendations into practical and used methods.

Different studies have tried to demonstrate steel construction's sustainable potential. For this reason, it was essential to evaluate to what extent steel solutions can achieve good results when assessed through the most common sustainability assessment methodologies. In the research presented in this paper, different methodologies were assessed and compared, when been applied to steel buildings. Although, all the methodologies evaluated can recognise some of the benefits of this construction solution, none of them is capable of addressing all the facts. If some can best recognise the functional or service qualities of steel buildings, as SBTool, others like LEED are more effective rewarding the steel recycling potential. BREEAM and DGNB showed a great coverage of the steel benefits, but in a superficial way. Also, early design support approaches should be preferable, since they contribute in a more efficient way to accomplish the buildings' sustainability.

Overall, to deal with all sustainable construction aspects, and in particular with steel construction, a systemic approach is needed, defining the sustainable building concept through tangible goals in order that, as a result of the sustainable design process, it is be possible to achieve the most appropriate balance between socio-cultural, economic and environmental fields.

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Defining best practices in Sustainable Urban Regeneration projects

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ABSTRACT: This paper aims at analysing three international sustainable urban regeneration projects. The analysis is based in the application of ten urban sustainability indicators from two sustainability assessment tools (Sustainable Building Tool for Urban Planning in Portugal - $SBTool^{PT}$-UP and International Sustainable Building Tool for Urban Planning– SBTool Urban) that are being developed at national and international level, respectively. Through this analysis it is intend to define the best practices for sustainable urban design, which allows to define the benchmarks of both tools and to support designers in the processes of decision making which goal is to optimize the sustainability of new or regenerated urban areas.

1 INTRODUCTION

Urban regeneration is on the agenda of many municipalities and nowadays it is perceived that this issue has an increasingly importance. Aspects like e.g. optimizing citizens' satisfaction are now in the basis of many urban projects (new or regeneration). At the moment the aim is not only to preserve the cultural heritage but also to avoid uncontrolled urban sprawl, avoid excessive use of natural resources while improving the population quality of life. It is known that every year buildings together with others constructions consume 40% of the global natural resources (Roodman & Lenssen, 1995) and current trends predict that the number of urban inhabitants will keep rising, reaching almost 5 billion by 2030 out of a world total of 8.1 billion (UN-Habitat, 2007). These data summarize the global concerns, and leave evidence that urban regeneration is considered as one of the fundamental mechanisms for achieving sustainable urban development (Turcu, 2012). Souza & Awad (2012) argue that sustainable development concerns are at the present more urgently in cities with considerable problems, but in future all cities would have to be based in sustainable principles, since they are the largest resources consumers and the largest generators of waste of the planet.

Recently, some urban regeneration projects stand out for their greater concern with sustainability, as well as his legacy. According to Dale & Newman (2009), urban regeneration has been seen as a tool to create "incubation zones" for sustainable development, and its application has been expressed on projects with long-term thoughts, targeted to the benefit of the citizen and city, with direct influence mainly in the project area - i.e., the plot. These projects are supported by principles of sustainability, which are responsible for the design of strategies and urban policies for renovation/regeneration of the cities/neighbourhoods.

However, there has been little research regarding to the benchmarking (good sustainability and conventional practices) in urban regeneration, mainly due to the relative infancy of sustainable urban regeneration (Hemphill et al., 2004b). Even knowing that sustainable urban regeneration projects promotes sustainable public policies or even sustainable cities, it is important to define, beyond good intentions, what are the best sustainability practices and the best quantitative/qualitative benchmarks, supporting urban planners in improving the results of their projects.

There are already some forums for exchanging experiences among cities, but it is necessary to highlight that there are no unique solutions and therefore each site and project require specific measures related to their own characteristics (Miana, 2010).

Europe is the continent with the largest experience in urban regeneration, prominently the UK, Germany and France (Couch et al., 2011). In this study three projects were analyzed in order to assess the best practices: Nations Park, Lisbon (Portugal); La Confluence, Lyon (France); and Queen Elizabeth Olympic Park, London (England). The chosen case studies have common characteristics, are based in the rehabilitation of old industrial areas that were abandoned or degraded, and are considered by responsible authorities as sustainable projects. Urban regeneration projects are generally linked to vacant spaces and or brownfield sites - regarded as urban voids -, and its principles revolve around the attempt to solve urban problems through economic, social, environmental and physical improvements (Roberts & Sykes, 2000), as the reuse of unoccupied buildings, as well the improvement of infrastructures, facilities and urban services.

Among the analysis of three projects from different regions it is possible to verify how urban regeneration strategies are being applied by local authorities in the search for more sustainable cities and improved citizen’s quality of life, respecting the environment and its natural resources.

2 HOW TO MEASURE BEST PRACTICES?

The goal of this paper is to set the current best practices, in relation to what is practiced both at national and in European urban regeneration projects. The process of establishing best practices will be based on the use of sustainability indicators, since they are fundamental instruments for urban analysis, for the design of policies, strategies, programs and actions for sustainable urban development (Rosales, 2011). The indicators are the basis to measure sustainability; however, one must be very careful in selecting the indicators to be used at each context because indicators to measure the sustainability of an urban area might not be useful for others.

2.1 *Sustainability indicators*

The indicators considered in this study are based in the work carried out in the development of the SBTool^{PT} methodology for Urban Planning (SBTool^{PT}-UP). This tool is still being developed and will follow the steps of the overall methodology, which considers a set of indicators related to different categories and evaluated by a set of parameters. These indicators along with their categories represent the three dimensions of sustainable development: environmental, social and economic. Scheduled for release in late 2013, this tool will allow assessing the sustainability of urban planning projects and urban regeneration, but also will serve as a guide for implementing best practices, supporting the development of more sustainable cities.

The structure of this methodology is being developed and adapted to the Portuguese context by the Laboratory of Building Physics and Construction Technology of University of Minho (LFTC-UM), based on the work of Serge Salat (Salat et al., 2011) and on the work of the iiSBE working group SBTool Urban (iiSBE, 2013), which is also in development. A cooperative effort is being made for the improvement of these methodologies taking into account the latest scientific developments in sustainability at the urban scale.

The process of developing indicators to the SBTool^{PT}-UP methodology was based the following goals: to create a list of indicators that is organized, transparent, objective and takes in consideration the most important aspects of sustainable development. This list was developed based upon the current state-of-the-art of existing methodologies to assess the sustainability of urban projects and urban communities and based upon the indicators of the building sustainability assessment tool SBTool^{PT}.

According to Bragança et al. (2013), the tool encompasses twelve categories under the scope of the main sustainability dimensions (environment, society and economic). Additionally, an extra category is considered covering the sustainability of buildings and information and communication technologies. The forty one indicators included in this tool, as well as the respective categories and dimensions, are presented in Table 1.

Table 1. List of categories and sustainability indicators of the SBTool^{PT}-UP methodology.

Dimension	Categories	ID	Sustainability indicators
Environment	C1. Urban Form	I1	Passive Solar Planning
		I2	Ventilation Potential
		I3	Urban Network
	C2. Land use and Infra-structure	I4	Natural Land Potentials
		I5	Density and Flexibility of Uses
		I6	Reuse of Urban Areas
		I7	Rehabilitation of the Built Environment
		I8	Technical Infrastructures Network
	C3. Ecology and Biodi-versity	I9	Distribution of Green Spaces
		I10	Connectivity of Green Spaces
		I11	Indigenous Vegetation
		I12	Environmental Monitoring
	C4. Energy	I13	Energy Efficiency
		I14	Renewable Energy
		I15	Centralized Management of Energy
	C5. Water	I16	Consumption of Drinking Water
		I17	Centralize Management of Water
		I18	Management of Wastewater
	C6. Materials and Wastes	I19	Sustainable Materials
		I20	Construction and Demolition Waste
		I21	Management of Urban Solid Waste
Society	C7. Comfort of Outdoor Areas	I22	Air Quality
		I23	Outdoor Thermal Comfort
		I24	Acoustic Pollution
		I25	Light Pollution
	C8. Safety	I26	Safety in the Streets
		I27	Natural and Technological Risks
	C9. Amenities	I28	Proximity to Services
		I29	Entertainment Equipments
		I30	Local Production of Food
	C10. Mobility	I31	Public Transportation
		I32	Pedestrian Accessibility
		I33	Cycle Paths Network
	C11. Local and cultural identity	I34	Public Spaces
		I35	Heritage Valuation and Landscapes
		I36	Integration and Social Inclusion
Economic	C12. Employment Pro-motion and Investment	I37	Economic Viability
		I38	Local Economy
		I39	Employability
EXTRA		I40	Sustainable Buildings
		I41	Information and Communication Technologies

3 CASE STUDIES

3.1 *Nations Park project*

Located in the eastern area of Lisbon, the Nations Park is an ambitious project that came up with the city's bid to organize the last World Exposition of the 20th century, the EXPO'98, with the purpose of regenerating a degraded industrial port area. The former industrial area, which had been abandoned, was totally obsolete, presenting soil contamination problems due to heavy metals and oil, but which held, however, great development potential due to its proximity to the Tagus River. The project consisted on urban and environmental regeneration of an area of 340ha which led to the modernization and internationalization of Lisbon, restructuring and rehabilitation, as well as the implementation of new accesses, transport, facilities, services and infrastructure, by demonstrating great care with the urban fabric.

3.2 *La Confluence project*

La Confluence is a contemporary proposal, which respects the historical legacy of the region. Located at the south end of Lyon's central peninsula, at the confluence of the Rhône and Saône rivers, it is a project that aims the renovation of an area of 150ha characterized by the development of an industrial suburb. Among the design principles is the extension of the current centre of the city, with the creation of generous public spaces, making the place accessible to all citizens, ensuring the social mix and balance of functions (housing, offices, leisure, commerce), and the sustainability of the city.

3.3 *Queen Elizabeth Olympic Park project*

The Queen Elizabeth Olympic Park is a project that demonstrates the UK experience in urban regeneration. The park is located in East London, more precisely in a region known as Lower Lea Valley, characterized by retaining the poorest neighbourhoods of the city. It was considered an area with the highest UK rate of unemployment, with low access to open spaces, isolated by poor access, the river and derelict land - although not far from the centre of London. The project combines the rehabilitation and decontamination of an area of 226ha, providing a new public infrastructure that will provide long term benefits to the residents of the city, including employment, housing, educational and recreational opportunities, and the development of sport and assurance to come to host the most sustainable Olympic Games to date.

4 RESULTS AND ANALYSIS OF RESULTS

From the list of 41 indicators of the tool SBTool^{PT}-UP, only 10 indicators were analyzed: 4 from environmental dimension, 5 from social dimension and 1 from the economic dimension (Table 2). In addition to ensuring that the indicators belonged to the three dimensions of sustainable development, the authors also have had a strict care to ensure that the basic characteristics of the indicators should be present in each case study in order to provide conditions for a proper comparison between them. Likewise, only the parameters whose data project is consistent with the assessment methods proposed by the tool were considered. The list of evaluated indicators and parameters and their results are presented in Table 2. The scores will be presented in percentage for a better understanding. Then, in the next subsections further explanations about the used indicators and obtained results are presented.

Table 2. Projects analysis – Performance at the level of each sustainability indicator.

Sustainability indicators	Parameters	London	Lisbon	Lyon
Reuse of Urban Areas	Percentage of decontaminate soil area	100%	100%	61%
Built Environment Rehabilitation	Percentage of existing structures rehabilitated and reused	0%	10,15%	44%
Distribution of Green Spaces	Percentage of green spaces	19,91%	32,35%	20%
Management of Wastewater	Index of effluent management	57%	50%	57%
Safety in the Streets	Index of safety on the streets	94%	88%	82%
Public Transportation	Index of quality and frequency of public transport	77,33%	76%	82,67%
Cycle Paths Network	Index of cycle paths network quality	87,5%	75%	94%
Public Spaces	Percentage of urban public spaces	45%	57%	43%
Integration and Social Inclusion	Percentage of affordable housing	34%	0%	25%
	Index of population participation	75%	33%	92%
Employability	Index of employability	100%	83%	50%

4.1 *Reuse of Urban Areas*

This indicator promotes the restraint of urban sprawl through the reuse of previously built areas and adequate treatment of contaminated soils (if any). All studied projects feature the reuse and soil decontamination. However in Lyon the development is partly in an existing area of the city with dwellings fulfilling nearly half the total area of intervention and another parcel previously occupied by industrial activities. Thus, their percentage of soil decontamination is less than the other projects, 61% of decontaminated soil area compared to the 100% in London and Lisbon.

Some regions do not include specific legislation on rehabilitation of contaminated soils, as is the case of Portugal (APA, 2013). Thus, based on the urban regeneration projects the best practice will be fixed an index of 100% of reuse of pre-built or contaminated areas.

4.2 *Rehabilitation of the Built Environment*

This indicator aims at promoting the refurbishment and reconstruction instead of new construction, maintaining the legacy and the built heritage of each site through sustainable practices rehabilitation. Thereby it promotes the efficiency of material resources, energy and water. In the London project there were no actions to preserve and rehabilitate existing buildings, since there were no buildings with architectural value on site. In Lisbon the situations is practically the same, since only one old oil refinery tower was reused. Nevertheless the project involved the reconstruction of two important pre-existent infrastructures: Doca dos Olivais (old dock) and Aterro Sanitário de Beirolas (sanitary landfill) - two important infrastructures for the area. Lyon stands out for the large number of buildings with historical and architectural value, and by the promotion of sustainable rehabilitation practices, providing different uses through the adaptation of buildings to current needs.

Based on studies conducted by Hemphill et al. (2004a) and the state of the art of the methodologies for sustainability assessment for urban planning, the best practice will be the index equal to or higher than 40% of the total built up area which has been reused and rehabilitated.

4.3 *Distribution of Green Spaces*

The primary objective of this indicator is to promote the protection and enhancement of local biodiversity. Nevertheless it also promotes other benefits resulting from the use of urban green spaces, which include: better physical and psychological health of the inhabitants; social cohesion; climate change mitigation; pollution reduction; biodiversity conservation; improvement of urban microclimate and air quality; increase of permeable areas of the city; and aesthetic benefits. Although the Lisbon project has the highest percentage of green spaces, these spaces are less uniformly distributed than in the Olympic Park and La Confluence projects.

According to Singh et al. (2010) there are some emerging trends from cities that promote the implementation of urban green spaces in 20-30% of the total area of the urban development/regeneration projects. A comprehensive study in 386 European cities (Gaston & Fuller, 2009) suggests that the coverage of green spaces vary significantly, with an average of 18.6%. Thus, based on these arguments and on data of case studies, the best practice corresponds to an urban regeneration project that presents the index equal to or higher than 25% of the total project area for green spaces.

4.4 *Management of Wastewater*

The purpose is to reduce the implementation of sewage systems and main drains by introducing in situ systems to treat waste and rainwater, allowing its reuse e.g. for irrigation and helping to reduce the occurrence of floods. This indicator is evaluated through the index of effluent management, through a qualitative process (checklist). In general, the analyzed urban regeneration projects feature concerns about effluent management. In all case studies the wastewater and storm water are treated on-site or nearby and reused for irrigation of urban green spaces.

Therefore best practice corresponds to projects that have a management plan for surface water that considers the principles and techniques of infiltration and percolation (for control of soil erosion), evapotranspiration (deployment and protection of green areas, green corridors), and include in situ treatment systems and reuse of water. According to the developed checklist and scores this means that the best practice corresponds to values equal to or higher than 55%.

4.5 *Safety in the Streets*

This indicator aims at promoting the safety of users of the urban area and crime prevention through urban design. The concern with pedestrian's safety is present in all projects, especially the Olympic Park which use the Secured by Design Principles as the basis of project. This indicator is measured by the index of safety on the streets, which is assessed through a checklist.

The best practice will be the project that presents the index of safety on the streets with values equal to or higher than 80%. The good performance of urban regeneration projects are based on the implementation of measures related to some key strategies: territoriality (orientation and dimensions of the plots, streets, and houses to encourage interaction between neighbours; accentuate entrances with different paving material, changes in street elevation and landscape design), natural surveillance (avoiding landscaping that might create blind spots or hiding places; distribution of mixed uses) and access control (designing streets to discourage cut-through or high-speed traffic; designing sidewalks in safe places for pedestrians, and use them to set limits). Another crucial dimension concerns the continuous and effective maintenance and management of urban space (maintaining common areas, lighting equipment and parking areas; keeping walks clean and repaired, lines of sight open, plantings and grounds in good condition), discouraging unused space (e.g. abandonment).

4.6 *Public Transportation*

The aim of this indicator is to promote best practice in mobility, enhancing the quality of public transports and local connections that they establish. The main target is to reduce the use of the private vehicles. Public transportation was highly valued in the studied urban regeneration projects. A wide range of transport modes are found, as well as great investment in infrastructure to improve quality or to create new means of transport, routes and accesses.

The performance of an urban regeneration project in terms of this parameter is evaluated by the index of the quality and frequency of public transport that comes from summing up the credits achieved in a checklist that covers topics such as: transport conservation status; existing options of transportation; existing infrastructure; average frequency of transport; proximity to stops, and quality of stops. The best practice will be the urban regeneration project that scores an index equal to or greater than 75%.

4.7 *Cycle Paths Network*

The objective of this indicator is to promote the use of bicycles as a viable option of transport (safe and quality) for movements between residential, educational, commercial and industrial areas. Thus it is promoted the use of no-pollutant means of transportation, serving as an alternative to the use of polluting transport. This indicator was evaluated through the index of cycle paths network quality, consisting of a checklist with variable factors. The three projects provide bicycle paths to its residents and visitors. Lyon Confluence, however, stands out by the quality of the implemented cycle paths which allow an index of 94%.

In order to obtain a good performance in this indicator, the urban regeneration project should first check and assess the suitability of the land to be frequented by cyclists. Once the area of intervention is able to implement cycle path, the project must contain an urban plan offering conditions for a healthier mobility by promoting the development of a quality cycle path network that is both embracing and secure for users. This network should be preferably combined with the different means of transport, be provided with facilities to support cyclists and to be attractive. The best practice will be the urban regeneration project that provides the index equal to or greater than 85%.

4.8 *Public Spaces*

The aim of this indicator is to promote the identity of local community through the implementation of quality public urban spaces. Analysing the projects, it is verified that a large percentage of the areas were destined to urban public spaces, with an average over 43%. This indicator allows assessing the percentage of quality urban public spaces within the urban regeneration project that are accessible to the population.

The best practice is a project which has an area of quality urban public spaces equal to or greater than 40% of the total area of the project. The quality and diversity of the public spaces along with the existence of a network of paths that connect public spaces are aspects that are assessed through a checklist.

4.9 *Integration and Social Inclusion*

The main goal of this indicator is to promote affordable housing to a broad spectrum of people (age, social class, religion, ethnicity, etc.), along with promoting the participation of the population since the preliminary design phases. This indicator is measured by two parameters, one quantitative and the other qualitative. Both the Olympic Park as La Confluence had great concern to promote social housing, allocating much of the new construction to this typology. The design of the Nations Park did not allocate a percentage of dwellings for social housing and the public participation in the project was little.

The best practice for the percentage of affordable housing is equivalent to values equal to or higher than 20% of the total housing areas. The best practice for the index of population participation, assessed by a checklist, is equal to or higher than 75% which corresponds to a project that: promotes the population’s participation through meetings, workshops, volunteering (ONGs); provides support for local business and enterprises; provides a strategic plan that includes a study showing the necessary number of social housing; provides different typologies of affordable houses (low-income families, students, young couples and disabled people), with different sizes and that are not apparently different from the others residences.

4.10 *Employability*

The aim of this indicator is to promote, through the urban regeneration design, the growth of local employment and professional training of residents. It is intended that the project set the basis to create strategies to promote local employment (temporary and permanent), during the construction and operation phases. This indicator is evaluated through the index of employability, consisting in a checklist with variable factors. London project showed best results, since one of the main aims was to solve a major problem that was identified in the Lower Lea Valley region: the high rate of unemployment. The London Employment Skills and Action Plan for 2012 promoted training courses and provided a National Skills Academy for Construction at the Olympic Park site which helped the Londoners to get employment with local contractors.

The best practice is an urban regeneration project that presents the index of employability equal to or greater than 75%. In order to obtain a good performance in this indicator, the urban regeneration project should perform an economic study covering aspects such as: business in existing area, unemployment rates, provision of facilities and location of business types. The project should also promote employability through the use of local workers, provision of training courses and promoting the increasing number of jobs and the local economy.

5 CONCLUSION

The analyzed urban regeneration projects proved to be good examples of sustainable projects, facilitating the definition of the best practices for the ten sustainability indicators of the tool SBTool^{PT}-UP. The levels of best practices were set by analysing three European representative projects, as well as considering other best strategies implemented at European level. The tool under development (SBTool^{PT}-UP) is also aimed to support designers in the development of more sustainable urban projects since the best practices are goals to be achieved, serving as an incentive for sustainable design as well for evaluations and comparisons between different projects or project scenarios. According to the national and international context on the sustainability of urban development operations the study presents itself as an important tool to promote sustainability for both Portuguese and around the world cities, since the best practices can be used to support the development of more sustainable urban areas or the regeneration of cities by setting tangible goals to be used by designers, architects, planners and governmental entities in the process of developing a more sustainable built environment.

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An Investigation of Indicators, Metrics, and Methods Used to Measure Green Buildings' Occupancy and Usage

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ABSTRACT: Recent research suggests significant health and productivity benefits in green buildings. However, these benefits have been difficult to measure and quantify. This study aimed to review the literature investigating building usage and occupancy. Specific objectives involved identifying 1) health, productivity and other performance indicators used in the literature to qualify building usage, 2) specific metrics used to quantify each of those indicators, and 3) specific methods used to compute those metrics. The study involved dividing indicators, metrics and methods into two main categories: one focusing on occupants' impact on buildings' performance, the other on buildings' impact on occupants. The ultimate aim of this study is to create a comprehensive database of existing building occupancy indicators, metrics and methods that can be used and improved upon by future researchers to quantify building occupancy. This should enable the establishment of post-occupancy evaluation protocols to address the missing link between occupants and buildings' performance.

1 INTRODUCTION

Buildings' features and physical characteristics can have significant effects on occupants' health, productivity and satisfaction given how people spend 90% of the time indoors (Gill et al. 2010). Similarly, occupants can also have a considerable effect on their indoor environment, and more specifically on their buildings' energy use(Guerra-Santin 2011). Many proponents of green buildings tend to focus on their energy saving potential. Although energy costs tend to represent the majority of a buildings operating costs, these operating costs represent a tiny proportion of companies' overall costs (Paul and Taylor 2008). In addition, several post occupancy studies of green buildings indicate that their energy savings may not be meeting their expectations (Scofield 2009, Deuble and de Dear 2012). Several reasons can be attributed to these observations. However, occupancy patterns seem to play a major role in shaping the energy performance of buildings (Stevenson and Leaman 2010). A study by Gill et al. 2010 indicated that 40% and 50% of the variations in electricity and heat consumption respectively, can be directly attributed to occupants' behavior.

Employee-related costs represent a much larger share of companies' expenditures than building operations costs. In order to provide a stronger argument for green buildings, proponents need to highlight their benefits that relate to employees' health, productivity and satisfaction. Showcasing the savings that green buildings incur on these costs, through improved indoor environment, would increase the marketability of green buildings. For example, estimates indicate that cost savings related to improved indoor environment can amount to $5-20 billion due to decrease in absenteeism and building-related illness (Fisk and Rosenfeld 1997). One of the main challenges in highlighting those cost savings is that their quantification is extremely difficult. Many of the performance and health benefits of improved indoor environment are difficult to measure and to be attributed to building features. The goal of this study is to create a database of all the indicators related to buildings' occupancy. Specific objectives include providing the metrics which can be used to quantify these indicators as well as the methods of gathering appropriate data for such indicators.

2 METHODS

A comprehensive literature search was conducted using the scientific databases of Scopus and Science Direct. Keywords used for the search included“occupancy, green, buildings, occupant behaviour, performance, productivity, health and indoor environment”. The research resulted in 130 papers in total. These were analyzed to identify the occupancy and usage indicators, metrics and methods used in each. Most of them were found torely solely on occupant surveys as a research method to study occupancy and were therefore discarded.Only 39 papers using more advanced techniques to account for occupancy were therefore analyzed.

The research involved creating a database to classify the identified indicators, metrics and methods. Studies were first classified into ones that studied occupant-related factors such as health and productivity and ones which studied energy consumption in relation to occupancy. Occupant-related parameters were divided into three main categories (i.e. Satisfaction, Health, and Productivity). For each category, a list of all related indicators found in the literature was drawn. For every indicator, relevant metrics used to quantify it and methods used to evaluate it were identified. This resulted in a comprehensive database of indicators, metrics and methods used to quantify building occupancy and usage.

3 RESULTS AND DISCUSSION

This study provides a comprehensive overview of all aspects related to building occupancy and usage. The interaction between occupants and their buildings is a complex relationship whereby buildings affect occupants and occupants impact buildings. A number of studiesinvestigated the effects of the indoor environment on people’s comfort, health and productivity (e.g. Huang et al. 2012). Several others investigatedhow occupants’ behaviour affectedbuilding performance, in particular buildings’ energy performance (e.g. Spataru and Gillott 2011). This section divides the results of the literature review into two subsections: one focusing on building livability and the second on building usage.

3.1 *Livability*

Livability reports on the effect of the buildings on occupants whether related to their productivity, health or satisfaction while building usage reports on energy consumption.

3.1.1 *Occupant Satisfaction*

Several methodologies have been usedto assess and measure the very subjective aspect of occupant satisfaction. Surveys tended to be the most common method used in the literature, with theones established by the Center for the Built Environment (CBE) at the University of California, Berkeley and the Building Use Studies (BUS) in Londonbeing the most referenced over the past two decades (Baird 2011). Both surveys utilized a seven-point Likert scale and shared othercommon aspects that made them suitable for use in hundreds of buildings (Baird 2011). The Probe studies went a step furtherby combining occupants’ perceptions with technical and energy data to benchmark those buildings against a wider dataset (Leaman and Bordass 2001, Zalejska-Jonsson 2012). These surveys investigated a wide range of indicators. Table 1 shows the most common ones assessed by the CBE and BUS surveys.

Table 1: Occupant Satisfaction indicators

Indicators	Beauty, Serenity, Color, Brightness, Perceived light quality, Glare, Ventilation, Perceived air quality, Temperature, Use of supplementary heating/cooling, Noise, Humidity, Overall satisfaction
Metrics	Likert scale (1-7)
Methods	Occupant Surveys

Other more objective methods were also used to evaluate occupancy. For example, Bluyssen (2010) developed a Building Comfort Index to report on building occupants' satisfaction using recorded and archived data. The index is based on dividing the number of complaints related to a specific building (e.g. heating, cooling light or noise complaints)by the number of occupants in that building.

Other studies used human resources data such as staff turnover, vacancy ages and average time to fill vacancies (e.g. Haverinen et al. 2003) as indicators of occupant satisfaction and comfort in buildings. Although these indicators can provide objective means to assess occupant satisfaction, they are also reflective of other aspects such as job satisfaction, making them problematic indicators to use to evaluate occupant satisfaction. This is because there might be no connection between how satisfied occupants are with the indoor environment with a specific building they work in and how satisfied they are with their job.

Several attempts have been made to develop mathematical models to estimate occupant satisfaction. A study by Kosonen and Tan (2004) developed one based on occupants' perception of the building's indoor air quality:

$$PD = 395e^{(-3.25C^{-0.25})} \quad (1)$$

Where *PD* = percentage of dissatisfied occupants, and *C* = a value for perceived air quality.

Although this and other similar models might be considered an improvement over more subjective qualitative methods, its results are dependent on some subjective parameters based on occupants' perception (e.g. perceive air quality). The accuracy of such models might also be an issue that would need more investigation.

3.1.2 *Occupant Productivity*

Several indicators were used in the literature to assess occupant productivity such as absenteeism (e.g. Kim and de Dear 2012). Absenteeism was usually expressed in terms of number of hours absent per month and was based on data collected from Human Resources departments in most cases. Some studies however, opted to survey occupants themselves to collect absenteeism data (e.g. Turpin-Brooks and Viccars 2006), raising concerns about the credibility and validity of this self-reported data.

In general, it is usually more difficult to develop indicators for productivity of "knowledge-work" such as problem solving, policy development or product development (Heerwagen 2000). Therefore, many studies opt to using survey data to account for productivity factors (Heerwagen 2000). Surveys may ask respondents to estimate the number of work hours affected by adverse IEQ conditions or their estimates for productivity increase. The data obtained in such surveys cannot be validated by human resources since they are all personal estimates. However, obtaining such data provides an indicator to the effect of buildings on their occupants' productivity as perceived by those occupants.

Other studies subjected occupants to psychological to investigate their psychological state (e.g. Lan et al. 2011 and Gou et al. 2012) and use itto determine their productivity as per Table 2. In those tests, metrics such as simple reaction time and choice reaction time are used to determine the productivity of employees. The results from these tests can be easily compared between buildings in order to determine the positive or negative impacts certain buildings have on their occupants.

Table 2: Occupant productivity indicators

Indicators	Metrics	Methods
Absenteeism	Number of hours absent/month	Self-reporting survey OR HR data
Work hours affected by adverse working conditions (e.g. poor IEQ, noise…etc)	Number of hours affected/month	Self-reporting survey
Direct effect of IEQ on productivity hours (Xu et al. 2012)	Number of productive hours' increase/month. Productivity % increase	Self-reporting survey
	Retail Facility (Romm and Browning 1994)	
Sales	Sales/square foot	Company Data
	Health care facilities (Bilec et al. 2010)	
Registered nurses/Patient care technicians productivity	Required number of hours/number of provided hours	Computer software
Total direct Care hours	Number of hours spent in direct care/patients in bed (PIB)	HR data
Direct care total non-productive hours (Non-Productive hours refer to hours paid to staff for paid leaves)	Percentage of non-productive hours	HR data
Total paid hours per PIB	Total paid hours/PIB include (includes paid leaves)	HR data
Labor costs per PIB	Total wages of all employees/PIB	HR data
	Call centers (Niemelä et al. 2002)	
Staff productivity	Number of telephone calls/the active work time	HR data
	Pre-fab production facilities (Ries et al. 2006)	
Staff productivity	Man hours/daily pounds of poured concrete	HR data
Safety	Number of accidents/ month	HR data
	Schools (Armijo et al. 2011, Issa et al. 2011, Roberts 2009)	
Student Performance	Exam scores average (Reading, Writing or Arithmetic)	School records
	PASS survey (Doesn't extend to classroom level)	Surveys for principals
	LER survey	Surveys for teachers
Absenteeism	Total number of days absents (students, teachers, or staff)/ month	HR data / School records
	Simulation of a work office environment (Newsham et al. 2009)	
Text typing	Characters/minute	Recordings via specialized equipment. Some of the indicators are evaluated using neuro-behavioral test packages on the computers.
Mathematical calculations	Units/min	
Grammatical reasoning	Units/second	
Visual learning	Memory capacity	
Creativity	Number of uses suggested	
Serial recall memory	Number of correct digits	
Anagram solving	Time taken to solve solvable anagrams, and time before giving up on the impossible anagrams	

3.1.3 *Occupant Health*

The direct effect of indoor environment on occupants' health has been demonstrated in the literature. Several studies indicated a direct correlation between the sick buildings syndrome (SBS) and ventilation rates in buildings (Muhič and Butala2004). In addition, the effects of buildings' indoor air quality on occupants' respiratory health were proven by several studies (Kosonen and Tan 2004). Given that people spend approximately 90% of their time inside buildings, developing indicators for health conditions affected by buildings' features was necessary (Kosonen and Tan 2004). Table 3 provides an overview of the health indicators used in current research for post occupancy evaluation of buildings.

Table 3: Occupant health indicators

Indicators	Metrics	Methods
Occupants' General Health (Herrin et al. 2012, Haverinen et al. 2003, Chiang and Lai 2002)	Number of days/month for which an occupant reports being ill from a list of maladies (e.g. respiratory infections, headaches and other SBS symptoms)	HR data OR Self-reporting surveys
Building Symptom Index (Bluyssen et. al. 2011)	Number of symptoms reported by occupants/ number of occupants	Self-reporting surveys
Absenteeism attributed to health problems (e.g. respiratory issues) (Singh et. al. 2010)	Number of hours absent for these specific reasons/month	Self-reporting survey OR HR data
Work hours affected by health issues (e.g. asthma, depression, stress…etc.) (Gou et al. 2012)	Number of hours affected/ month	Self-reporting survey
Psychological state of occupant (KosonenandTan 2004)	Simple reaction time, choice reaction time…etc.	Psychological testing
Physiological parameters (e.g. finger temperature, heart rate…etc.) (Bluyssen 2010, Mootz 1986))	Average heart rate, finger temperature…etc.	Specific equipment

3.2 *Building Usage*

Quantifying the usage patterns of building occupants is one of the main challenges for building researchers. Several methodologies have been reported in the literature which attempted to measure and quantify occupant behavior. This section attempts to present the different methodologies that were reported in the literature for measuring occupant-behavior. Jain et al. 2013 assessed the impact of energy consumption feedback on occupant behavior in a New York City residential building. The study monitored electricity consumption using data loggers connected to current transducers. The data loggers were installed in the basement of the building to monitor the specific rooms. It is important to note that the building was already equipped with sub metering for its units which facilitated the connectivity of data-loggers. The reported consumption, which was collected every 10 minutes, was divided by the number of occupants to estimate a usage profile for each occupant. One of the limitations of this study was that it only captured electricity consumption which is only one component of energy consumption. In addition, dividing the total consumption by the number of occupants doesn't provide an accurate usage profile for each occupant. A study by Menezes et al. 2012 reported utilizing a similar methodology but applied it to an office environment. The study collected electricity consumption data from sub-meter readings and 3-phase to data-loggers connected to the sub-circuits. Additional data was gathered using plug monitors and loggers connected to individual office equipment. The consumption data was correlated to occupancy patterns by manually counting the numbers of occupants.

Another method for quantifying occupancy was reported in a study by (Spataru and Gillott

2011). In this study, an RFID system was installed around the building in order to track occupancy patterns. Occupants were required to wear RFID tags in order to be detectable by the system. The monitoring system also included sensors for temperature, humidity, and air quality in order to include IEQ in the study. In general, energy consumption data was gathered and correlated using computer software to the occupancy patterns data from the RFID system. A strong correlation was demonstrated between occupancy and energy consumption (Spataru and Gillott 2011).

A simpler methodology for quantifying occupancy was reported in the study by (Martani et al. 2012). The study gathered electricity consumption data at a university campus, where the energy data was divided by the total area of the studied academic spaces. Occupancy was then determined by gathering data from the Wi-Fi operator regarding the number of computers connected to the Wi-Fi system. The study demonstrated a strong correlation between the energy use profile for each space and the number of occupants connected to the Wi-Fi network in that space. Although this technique doesn't capture the exact number of occupants in every space, it still provides a good estimate for the actual number of occupants in a space. It is also a relatively cheap and easy to apply technique which can be easily reproduced in other studies.

4 CONCLUSION

Although many of the identified studies indicated a strong relationship between occupancy and buildings, quantifying occupancy indicators remains a difficult task. This study provided a comprehensive dataset of indicators that can be measured in different buildings with relatively easy mechanisms. However, standardizing which indicators to use and the methodologies for obtaining occupancy data is essential in order to enable comparisons across buildings. Green buildings can have significant positive impacts on their occupants which are not usually considered when evaluating their lifecycle. Creating standard indicators with clear metrics for occupancy can overcome this challenge and provides a stronger business case to support the green buildings' industry with quantifiable data. In addition, exploring techniques that reveal the role of individual occupants on buildings' energy consumption can help in reducing overall buildings' energy demand which is much needed in today's world.

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From lighthouse projects to sustainable building stock

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ABSTRACT: In order to fulfil the EU 20-20-20 targets, the European building stock has to be refurbished sustainably. To stimulate this refurbishment, the owners of large stocks need for each building reliable information about which measures are necessary, ecologically worthwhile and at the same time economically reasonable. Based on the German DGNB indicators, the software module epiqr® NC renders possible the assessment of sustainability even for large building stocks and gives precise information on the cost of sustainability.

1 INTRODUCTION

The refurbishment of buildings is one of the key strategies of the European Union in reaching its 20-20-20 targets (EU 2012). Therefore it is necessary to increase the sustainability of large building stocks, which means whole districts and portfolios have to be sustainably refurbished. This, however, is still rather an exception. Not for nothing do we refer to lighthouse projects when individual buildings are awarded a certificate for sustainability. Instead, to reach the goals for 2020 and 2050, 2.5% of the total EU building stock would need to be sustainably refurbished each year for the next 40 years, compared to the actual 1% (BPI 2011).

In order to accelerate this development, we need reliable information concerning the actual state of the building stock and the cost of its sustainable refurbishment. Indeed there are diverse certification systems, such as LEED (LEED 2013) or DGNB (DGNB 2013), to assess buildings, but their methods are very time-consuming and cost-intensive. On this account they are used to examine the sustainability of a few new buildings – the lighthouse projects already mentioned. As these methods are, however, completely uneconomic for large building stocks, those are usually not being analysed. Consequently we are unable to make any statement about their state of sustainability. Yet, without this knowledge, it is impossible to estimate what has to be done to render them more sustainable and how much it costs.

When it comes to the decision whether to improve a building stock energetically or not, the fundamental criteria are after all the cost efficiency and calculability of this investment. In order to overcome this problem, the software module epiqr® NC has been developed. It facilitates a fast, simple and cost-efficient analysis of the sustainability of large building stocks as well as the planning of measures and expenses for their sustainable refurbishment.

2 THE EPIQR® PRINCIPLE

In 1995 an EU project developed criteria for the standardized assessment of portfolio properties. The result of this European research in the real estate sector was a method called epiqr® (EU 1996). The approach of epiqr® is unique: few geometrical factors are assessed systematically and only the degradation state of the most important building components is evaluated. In order to determine costs reliably and efficiently, the system deduces the necessary, but initially unknown, quantities by calculation and statistical extrapolation (Wetzel 1999).

An example of this statistical approach is the calculation of the glazed area of apartment buildings: in the conventional approach either the areas are calculated from plans or – as in most cases (reliable) plans are no longer available – the areas are measured with laser meters or other tools. A statistical survey however gave the result, that in 95% of all surveyed buildings the maximum deviation was 3% to the given ration of 1/6 for the window area to the gross building area (cp. fig. 1).

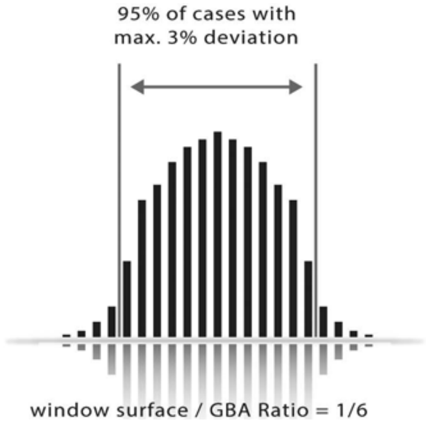

Figure 1. Statistical results for the glazed area of apartment buildings.

The assessment of so far over 120,000,000 m^2 gross building area helped to validate and improve the system. Based on the survey data the software calculates automatically the cost for maintenance and refurbishment. After the first overview of the whole building stock and according to first decisions which buildings should be improved, which should be maintained and eventually also which should be sold or demolished, maintenance and retrofit measures can be planned for each building in detail, based on a validated cost and measure database.

3 EPIQR® NC – THE SUSTAINABILITY-CHECK

3.1 *Simplified sustainability assessment*

Based on the epiqr® principle, epiqr® NC facilitates a cost-effective assessment of the sustainability of individual buildings or whole portfolios. For this the assessment criteria of the German DGNB-System (DGNB 2013) were analysed. Then the most important ones got simplified according to the Pareto principle. Thus a new system for the assessment of sustainability was developed: it is using fewer assessment criteria and can do without time- and cost-intense measurements and calculations.

Instead, the analysis of the actual state of sustainability is accomplished comparatively simply by an on-site inspection. In this way existing deficits in sustainability are quickly identified. A holistic analysis of the whole portfolio is guaranteed as well, as the ecological, economical and sociocultural quality of a building is being examined. Diverse criteria have been defined for each of these three columns of sustainability (cp. fig. 2). These criteria were in turn divided into different indicators, as shown in figure 3. The column sociocultural quality includes, for example, the criterion ”life cycle yield“, that consists of the indicators “rental success“, ”vacancy“ and ”object quality“.

Figure 2. The three columns of sustainability and their criteria.

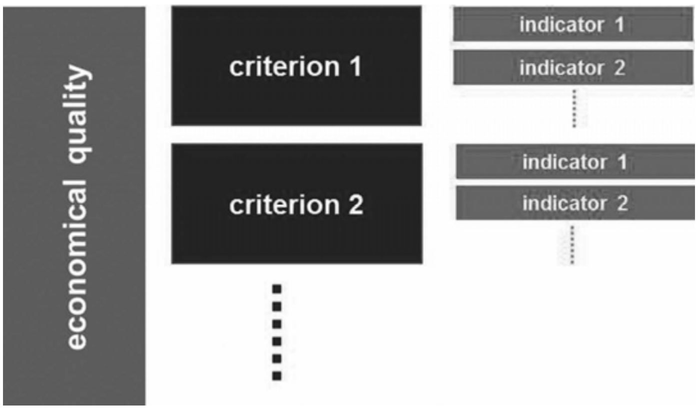

Figure 3. The different levels of the assessment of sustainability.

With the help of a question it is possible to decide, which state of sustainability each of these indicators manifests. For instance, in connection with the criterion „global warming potential“ there are, among others, questions about power consumption and about the energy sources used for heating. According to the answers the indicators can be allotted to one of four possible states, that are denominated from A to D. ”A“ represents the best possible and consequently most sustainable result, whereas “D“ describes the worst result (an example is given in fig. 4). In this manner all indicators can be assessed during the inspection.

According to epiqr® NC, a building is regarded as sustainable if all criteria have been assessed at least with state “C”. One assessment with “D” constitutes a veto: this means that its state lies below the defined critical value for sustainable buildings.

The overall result is depicted in the so-called epiqr® diagram (cp. fig. 5). Here it is possible to see directly, whether a building is sustainable and where there is still need for refurbishment. All criteria of sustainability are arranged clockwise and their state is depicted in form of a bar: the longer this bar, the worse the respective state. When the bar`s edge is coloured red, as in the right picture, this means that state ”D“ is reached and the building can no longer be regarded as sustainable.

Cooling-system: How is the building being cooled?			
A	**B**	**C**	**D = veto**
Natural cooling: natural ventilation, over-night-cooling, water-to-air heat exchanger	The building is cooled with a thermic heat exchanger, whereby the hot water comes from district heating, industrial waste heat, solar plants or combined heat and power plants. - Adsorbing and absorbing cooling device - Solar cooling	The building is cooled in an electrical way (compression cooling device).	-------

Figure 4. Question concerning the ecological quality.

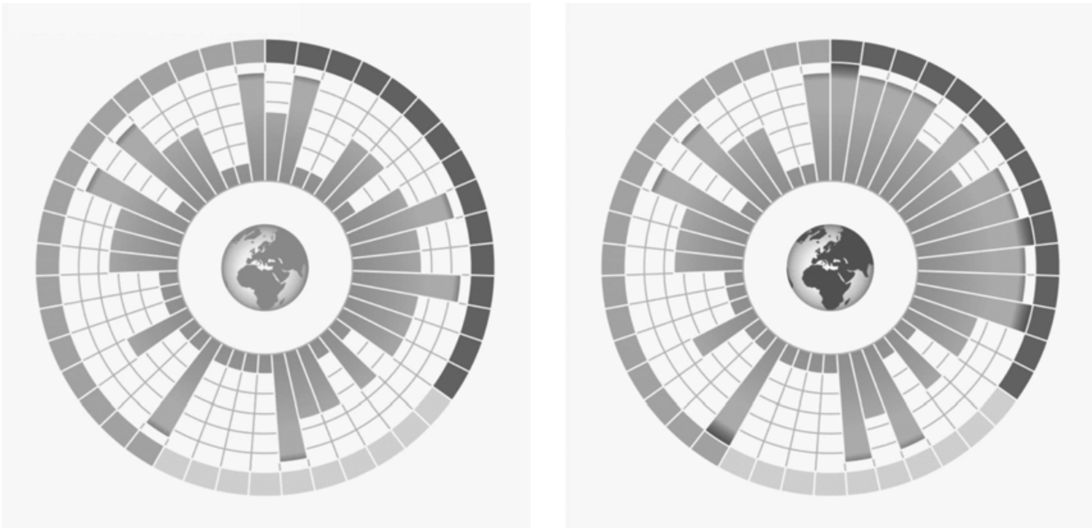

Figure 5. Presentation of a sustainable (green globe in the middle) and a not sustainable (red globe in the middle) building in the epiqr® diagram.

Using the software module, it is also possible to make a statement as to if a building can be certified according to the system of the German Federal Ministry of Transport, Building and Urban Development (BMVBS) (BMVBS 2013). This certificate can be obtained when all criteria are in state “A”, which is consistent with the reference value for a sustainable building (cp. fig. 6). In this connection the levelling board of epiqr® NC has consciously not been placed too high, as the target values of most certification systems are only seldom up to reality.

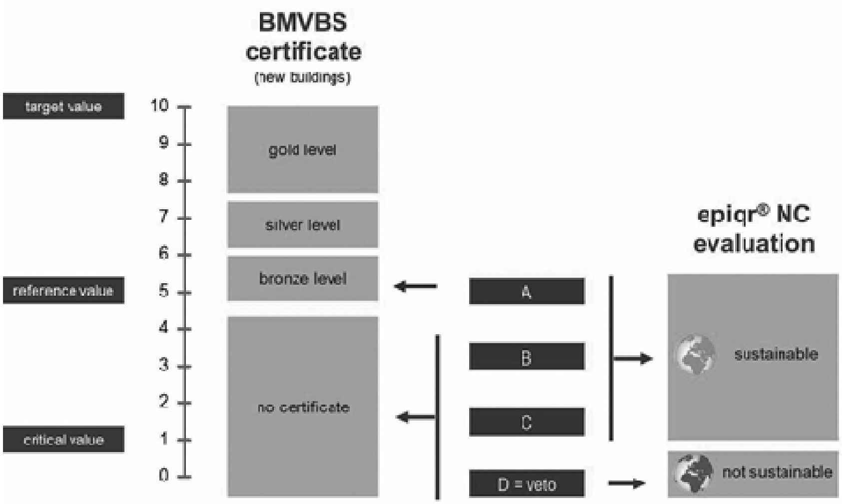

Figure 6. Comparison between the assessment with epiqr® NC and the BMVBS certificate.

3.2 *The cost of sustainability*

epiqr® NC has an extensive database at its disposal that helps to make sustainability commercially projectable as well. It contains for each criterion the different measures that are necessary to change it from any possible state into state ”A“. An example is shown in figure 7.

Rain/grey-water: Are rain or grey-water or taps that save water being used?

epiqr® NC state	description	measure
A	Rain/grey-water AND/OR taps that save water	No intervention
B	Omitted	Omitted
C	None of both	Installation of water-saving tabs Additional measure: change to rain/grey-water usage
D	No veto criterion	Therefore not existing

Figure 7. Example of possible measures to raise sustainability.

The database also provides the costs of these measures. The system is using them to calculate autonomously which expenses are necessary to make the building more sustainable. Thus epiqr® NC provides a reliable fundament for the planning of the sustainable refurbishment.

On this basis different scenarios of modernization can be planned and their costs compared without much effort. Thus it is possible to identify the optimal maintenance measures from an ecological, economical and at the same time sociocultural point of view. Finally dependable statements can be made about where exactly how much has to be invested to reach the desired degree of sustainability in a building stock.

4 CONCLUSION

The lever to a more energy efficient real estate industry lies doubtlessly in the building stock. With the fast and simple method of epiqr® NC, sustainability is no longer limited to a few light-house projects, but becomes practicable for the broad mass of buildings. Furthermore this tool answers the most important question concerning the decision whether to improve a building conventionally or sustainably: How much does "more sustainability" actually cost?

This is so important an issue, as sustainability is far more than just some prestigious marketing project or a perforce measure to achieve some abstract climatic goal. When it comes to portfolio management, sustainability is rather the task of preparing a building for the challenges of the future. It has to be regarded hence as coequal with topics such as yield and maintenance of substance. Combined with precise information on cost, it now meets this role`s requirements also from an economic point of view.

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Modelling Moisture and Site-Related Information for Sustainable Buildings

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ABSTRACT: In this paper, an approach for the modeling of moisture- and site-related information for sustainable buildings is presented. Aiming at integrating and extending current efforts describing a building's profile (or various aspects of it), the presented model integrates information related to the moisture performance of a building, including parameters referring to site-scale. Information of different nature and levels (spatial coordinates, building materials' properties, etc.) is included in the model. The moisture profile of a building modeled in this work can be used by several parties throughout the building's lifecycle to record, exchange and process information and is semantically described allowing for its easy integration and extension with other semantically described information. The proposed model can be used in the context of buildings' environmental profiles assessment, since moisture in building elements is related to various aspects of a building's performance, and also by various (semi-)automatic reasoning software tools in order to provide insights that are not easily recognizable by humans.

1 INTRODUCTION AND BACKGROUND

1.1 *Moisture profile of a building and building sustainability*

The presence, accumulation and periodic variations of moisture inside building components are related to various aspects of a buildings environmental performance. Indeed, with water either acting as the major aggressive agent or indirectly, facilitating the action of other deteriorating factors, moisture in building components is related to several building materials deterioration types and mechanisms (Fagerlund, 1996). As a result, it is highly correlated to the maintenance and the replacement needs throughout the building's life-cycle; therefore, it affects both the environmental impact of the building (need for new materials or reduction of the functionality of the components leading to the need of further resources consumption) and economic costs during the building's service life. Furthermore, it is strongly correlated to the energy performance of buildings, since it affects, among others, the thermal conductivity values of the insulating materials. Additionally, moisture induced damages in building components have been correlated to health problems among the occupants (Bornehag et al. 2004). All these lead us to claim that the moisture performance of a building affects key-factors of this building's environmental profile and should therefore be systematically taken into consideration in the context of the respective assessments.

In this work we propose a model for moisture-related information storage, retrieval and integration that can be used for the description of a building's moisture profile, can be extended to include other features related to a building's environmental performance and can be unified with other building environmental performance- oriented models. The structure and characteristics of the model are analytically described in the following sections.

1.2 *Information Integration*

Publishing data at a large-scale, which means that many different and diverse datasets will be made available to the end users, is a topic of vast interest encountered under the notions of big data and semantic web. Users are usually interested in combining information crossing through the available datasets regardless of origin, purpose or format. This means that we need to deal with data integration issues at various levels and with various degrees of coupling. In our case a seamless way to integrate data dealing with buildings, climate and sensor devices is needed.

Data integration means, among other things, that we need to provide end users with the notion that a single common well-managed data source exists instead of many – distributed or not – individual ones. In computer science, the database community has introduced the concept of *integrated data-spaces* (Franklin et al. 2005, Halevy et al. 2006) as a response to this problem. Integrated data-spaces should make use of techniques that infer relationships between data sources and that refine them in the light of additional information extracted from related data sources. Linking disparate datasets is also the objective of the recent W3C *Linked Open Data* (LOD – http://www.linkeddata.org) initiative for a unifying, machine-readable data representation that makes it possible to semantically access and interlink *heterogeneous* but also *(semi-) structured* resources at data level – no matter what the structure of the data is, who created it, or where it comes from. Exhibiting a higher degree of interoperability (than documents) and ease of reuse, Linked Open Data has become a prominent choice for sharing (semi-) structured data on the web originating from heterogeneous sources (Enterprises, Scientific communities, Press institutions, but also emerging Social Media applications). Linked Open Data offers great potential for building innovative applications that create new value from the already collected data. Thus Linked Open Data is an effort of integrating semantically described data on RDF and thus, can be used for the creation of *semantically interoperable data-spaces*.

Finally an important part of publishing data as Linked Open Data is the ability to employ URIs as the unique (and hopefully persistent) identifiers (IDs) for each data object published. URIs (Universal Resource Identifiers) have been proposed early enough in the semantic web initiative (Berners-Lee et al. 2005) as the main mean for resource identification. A constant problem, that the semantic web is facing, is the lack of a global authority that would be responsible to assign such URIs. Since such a task would definitely have a sequence of implications on the operation of the semantic web the chosen path of action in this area has been the assignment of URIs at the highest possible level. As described in the next section, we identified the possible URI-issuing issues for the involved datasets and discuss solutions where needed.

So the main contribution of this work besides providing a conceptual model that can adequately be used for storage and retrieval of information related to moisture in buildings is the ability to use the information model for integration information purposes; this would allow potential users to combine information on construction, architecture, energy, moisture and other aspects in order to be able to query across the different facades of information.

1.3 *URI construction*

A Universal Resource Identifier (URI) (Berners-Lee et al. 2005, Dittrich & Salles 2006) serves to uniquely identify information objects or real world entities in RDF data, be they local or published on the Internet ("Semantic Web"). URLs are a special case of URIs, with a particular syntax. They normally identify the location of a document on a server visible on the Internet. If the content of the document is changed, the URL stays the same, unless the operator of the site takes care to change also the URL in order to maintain a unique relation of the document to the URL. Therefore, it is a good practice to identify the document itself by a location independent URI (more good practices on URI construction can be found at: http://www.w3.org/2011/gld/wiki/223_Best_Practices_URI_Construction and other generic suggestions from EU bodies like EU commission regulation No 1089/2010 and EU commission regulation No 1205/2008 do exist).

URLs can also point to a non-existing document name on an existing server. This is exploited in the Linked Open Data protocol for identifying real world entities different from Web content. The server should redirect a request to such a URL to a page describing which real world entity is meant, for instance a person, a location, a particular instrument etc. Whereas for other URIs it may not be obvious where to find a description of what they stand for, the LOD URLs lead you on the Semantic web to the definition. However, if the service providing the definition goes out of service or changes name, the access to the definition is also broken, and the URL is not better than any other URI.

The worst case for information integration is, when everybody declares a new identifier for something, without others knowing. From a use point of view, we have to consider three basic questions: (1) how will I know that an object has gotten an identifier at all; (2) who will be able to confirm that the object is indeed identified by this identifier, and what that means; (3) how will I be able to find the object if you give me only an identifier. After this, the question that might appear is what to do if an object has more than one identifier, or if an identifier is used wrongly in a description. This brings forward the need for central authorities to govern the assignment and resolution of URIs. In our case there is to the best of our knowledge no such authority that can assign unique identifiers to buildings and the related information. On the other hand, authorities that publish e.g. climate data already provide unique URIs for their datasets.

It is to be expected that organizations introducing LOD identifiers at a later time, will follow a method, which will allow for automatically matching our "pseudo LOD identifiers" with the future correct LOD identifiers.

1.4 *Related work on modeling Building Information*

Various efforts have been reported so far in the process of modeling the information that needs to be maintained for buildings; one such notable effort comes from the EU-funded IntUBE (East 2010) project where there is an effort to model the whole building lifecycle from design to maintenance. They have introduced Internet Foundation Classes (IFC) to store structural and architectural information about a building. This work has become a standard in the area but is complementary to our work since we are interested in capturing the dimensions that affect the moisture profile of the building, information missing or only slightly touched in the IFC model.

DOE-2 (www.doe2.com) is another modeling effort mainly targeted to energy efficiency issues; a high profile issue for buildings the last few years. This is also complementary to our work since we do not work on the energy efficiency part of the building but since moisture can have an effect on the energy efficiency of a building (either as a result of lack of it or as an indication of wrongdoing) one ideal work would be to combine such efforts.

None of these efforts employ Linked Data principles in order to combine the necessary information in an open and extensible way; on the contrary these efforts end up with the production of (quality) but closed software, which uses and produces data that are neither reusable nor open to other users or applications. In a world where the quantity of data is increasing constantly it is of vast importance the capability to combine and reuse.

Finally, the effort by König et al., 2011, is close to our proposal in the sense that it also proposes an ontology to capture information related to buildings. The main difference here is that this work deals again with the energy profile of a building. It is worth to note though that unifying both profiles (energy and moisture) can be an extremely useful extension to both works; in any case it seems reasonable that we should aim for a unique global and comprehensive profile for each building covering all kinds of aspects that arise through a building's lifecycle.

2 A BUILDING'S MOISTURE PROFILE: REQUIRED INFORMATION

The moisture profile of a building covers a wide range of buildings' performance – related parameters (indoor air relative humidity, moisture content levels and variations inside and on the surface of building components, occurrence of interstitial vapor condensation, etc.) and is related to several building performance indicators. Moreover, a building's moisture profile, which is not static in time, is affected by several factors, varying with regard to their nature and type and to the severity of their influence (building component's layout and building materials, moisture loading resulting from climatic conditions, geometrical characteristics of the building itself, as well as of the adjacent buildings, etc.). As a result, the assessment of a building's moisture profile, given additionally the dynamic nature of the involved characteristics and parameters, is a complex procedure, requiring a plethora of information for its evaluation. In the presented model, we integrate the information that forms a sound basis for the moisture profile of a building to be identified and assessed. This information can be categorized as follows:

- Geometrical and morphological characteristics of the building: Information referring to the height and to the width of the building facades are essential for the estimation of the exposure levels of the building envelope's different parts to driving rain (Choi 1994, Etyemezian et al. 2000, Karagiozis et al. 1995, Künzel 1994), which is the main cause of water penetration into vertical building components. Also, such information facilitates, in combination to relative data for the neighboring buildings, the estimation of the building's access to direct solar radiation, which is critical for the building components' drying potential.
- Information related to building components: Information referring to the building components types and layouts (layers' thicknesses, building materials, relative position of layers in the component) are necessary for the moisture profile of the building to be assessed. For example, a component comprising a vapor barrier presents a significantly different hygrothermal performance than the exact same component without the barrier. Furthermore, the hygrothermal properties of the building materials consisting each component are included in the model: water absorption factor, thermal conductivity, vapor diffusion resistance factor and other properties are used in the context of calculations of building components' moisture profile. Moreover, information about the envelope's "weak" areas' (thermal bridges) existence, type and extent are included in the model: due to the inadequate thermal protection along or at these areas, moisture-induced problems often occur there.
- Information related to mechanical and electrical equipment of the building: The information belonging to this category is mainly related to the indoor air temperature and relative humidity values, which are necessary for the hygrothermal simulations, as well as for the detection of components that are subjected to severe loading. The information included in the presented model refer to the existence of a heating/ cooling model, its automated or manual operation and the set-points for temperature and relative humidity of indoor air during heating and cooling seasons. This estimation is useful not only with regard to the hygrothermal calculations but also with regard to the assessment of living conditions inside the building.
- Information derived from observations: In this category, information derived from recordings and information derived from inspections is included. Recordings of indoor air temperature and relative humidity, of surface temperature on building components and of moisture inside the components belong to the first group. The second group consists of observations of moisture-related damages (Fagerlund 1996) occurrence, such as mold formation, spalling, efflorescence, etc. These two groups are intended to provide an image of the actual moisture profile of a building and of this profile's alteration with time. Also, the second group can be used to provide indications for moisture-related problematic events in a building.
- Site-related information: The information that refer to site-scale and is integrated into the presented model, is grouped into two major categories: urban geometry and climatic data. In the first category, information related to the building's neighborhood are included, so that an estimation of which building facades are directly exposed (and to what extent and degree) to climatic loadings can be derived. The climatic data that include several climatic parameters (air temperature and relative humidity, wind speed and direction, precipitation, solar radiation, etc.), is essential for both a first estimation of the moisture load burdening building components and for the computational analysis of building components' hygrothermal performance with the use of appropriate tools (e.g. WUFI Pro4, MOIST, DELPHIN). With the hygrothermal analyses conducted with the use of sophisticated tools aiming at outlining the response of the building components to the dynamic loading imposed by the climatic conditions, the availability of hourly time-resolution data would be preferable.

The information described above is organized in the proposed model in a way that is analytically outlined and described in the following section.

3 MODEL DESCRIPTION

The proposed model covers all aspects of required information as detailed in section 2 of this paper. The model depicts the main concepts, which are noted as classes in the ontology world notation and their basic relationships, which are noted as relations in the ontology notation. Figures 1, 2, 3 depict the core ontology including both the concepts and relationships.

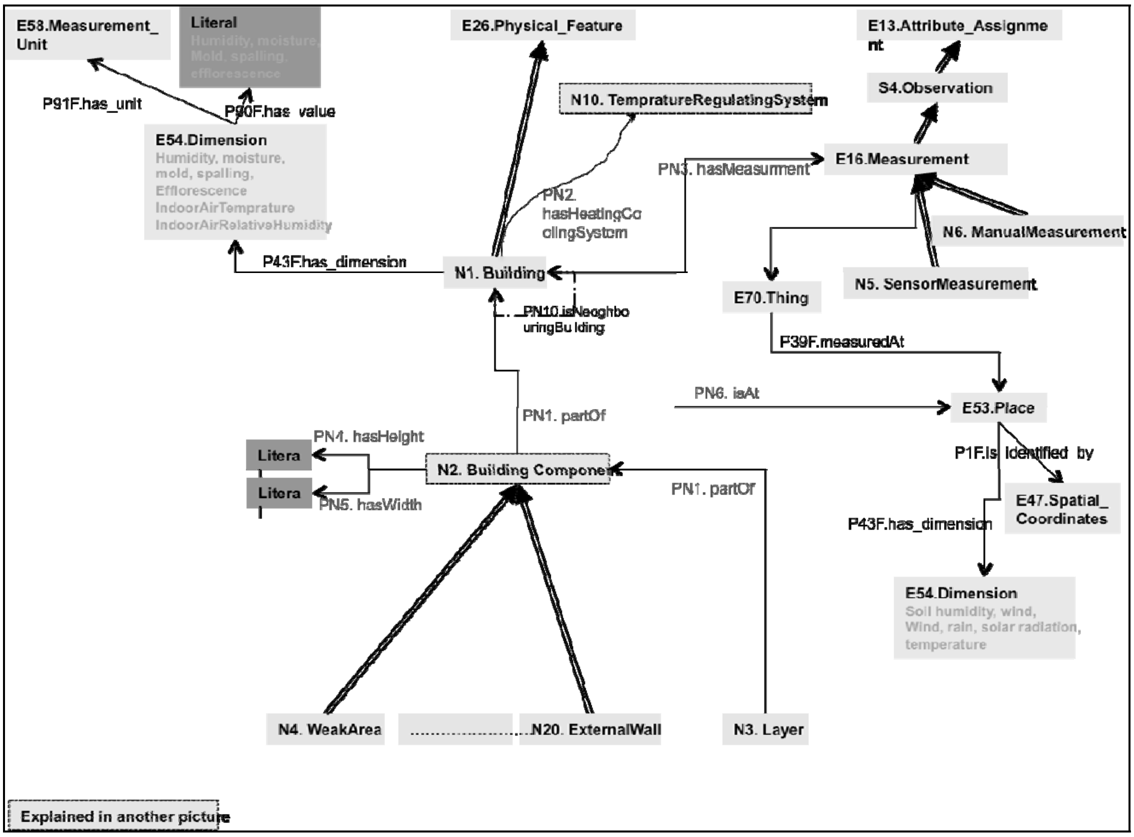

Figure 1. The main part of the Building Moisture Ontology

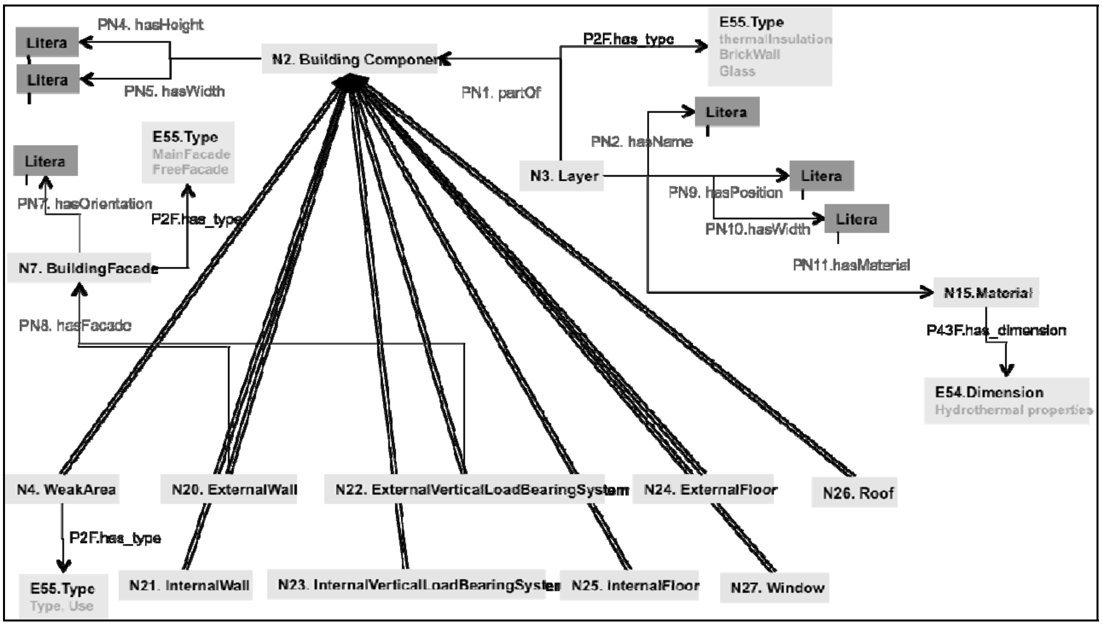

Figure 2. The analysis of the Building Component

In our model (N1. Building) is an enclosed construction over a plot of land having a roof and used for a variety of human activities (residential buildings, office buildings, schools, hospitals, factories, etc.).

The building in our model comprises of several building components (N2. Building Component), defined as building elements – subsystems of the whole building, which are usually consisted of more than one building materials and have specific functions in the whole assembly of the building. The building components in our model can be one among the following:

– N4. WeakArea: it represents the thermal bridges of the building's envelope.
– N26. Roof: the exterior surface and its supporting structures on the building's top.
– N20.ExternalWall: defined as a wall having one of its surfaces outside the building, exposed to the outdoor air or to the ground. The load bearing walls are not included in this category.
– N21. Internal wall: defined as a wall having all of its surfaces inside the building
– N24. ExternalFloor: the lower horizontal surface of the building.
– N25. InternalFloor: the horizontal surfaces between the different levels of the building.
– N22. ExternalVerticalLoadBearingSystem: The vertical load bearing structure of the building (concrete columns, concrete walls, load bearing walls, e.g. stone walls, etc.) having one of its surfaces outside the building, exposed to the outdoor air or to the ground
– N23. InternalVerticalLoadBearingSystem: The vertical load bearing structure of the building (concrete columns, concrete walls, load bearing walls, e.g. stone walls, etc.) having all of its surfaces inside the building.
– N27. Window: defined as any opening on the building's envelope.

The vertical external building components (N22, N27. N20.) are parts of the building's façades (N7. BuildingFacade), i.e. the exterior sides of the building enclosure; In the context of the study's scope, the facades of the building are classified into (N8. freeFacade), defined as the side of the building facing a space or a street (i.e. exposed fully or partly to the direct impact of climatic conditions), and (N9. mainFacade), defined as the front side of the building. Each one of the building facades is assigned an orientation (degrees, with 0º corresponding to North), so that the direct solar radiation and the driving rain load on it can be estimated on the basis of other information kept in the model.

The information kept in the model for N4. WeakArea are its length and its type, the latter depending on the cause creating the thermal bridge (geometrical or/and constructional) and on their position in the building (vertical, horizontal or openings' thermal bridges). Several types of thermal bridges can be registered in the model, e.g. discontinuance of vertical component's thermal insulation at the slab. The information kept in the model for the rest of the components (N20-N27) is related to the layers of their layouts.

In our model (N3. Layer) is defined as a single thickness of building material, which in combination with other layers forms the building component. The layers may be of several types: thermal insulation layer, brick wall layer, concrete layer, wooden material, wooden products and boards, plaster layer, natural stone layer, bituminous layer, screed layer, lightweight concrete layer, earthen materials, metallic layer, glass layer, plastic layer, air layer. For each layer, the information that is kept is its name, its relative position inside the component (natural number, with 1 corresponding to the outer layer of the component), its thickness (m) and its N.15. Material, i.e. the specific building material of which this layer is made (e.g., for the thermal insulation layer, the material could be extruded polystyrene, cellular glass, cork, expanded polystyrene, etc.). The information recorded for the (N15. Material) are the values of its hygrothermal properties; these properties include but are not restricted to thermal conductivity, vapor diffusion resistance factor, water absorption factor, density and heat capacity.

The building in our model also has electromechanical installations for heating and/or cooling, (N.10. TemperatureRegulatingSystem), which is classified into (N11. HeatingSystem), defined as a mechanism for maintaining indoor air temperatures at an acceptable level usually during cold periods, and (N12. CoolingSystem), that is the respective cooling mechanism. The heating system is classified into (N16.ManualHeatingSystem), i.e. heating, the operation of which is regulated and controlled by the building's occupants, and (N17.AutomatedHeatingSystem) that is defined as a fully automated system, the operation of which is not controlled by the building's occupants. The same classification is made for the cooling systems. For the automated systems, information referring to the set points of temperature and rel. humidity during winter and summer periods (E54) are kept in the model.

Furthermore, information derived from measurements of moisture-related quantities in the building are also modeled (E16. Measurement). The measurements can be either made with the use of automatic or semi-automatic equipment, e.g. sensors, recording at regular time intervals (N5. SensorMeasurement) or manually, e.g. occasional recording of moisture-related quantities or/and inspections, (N5. ManualMeasurement).

Also, information relative to the location of the building is kept in the model, in the form spatial co-ordinates (E47. SpatialCoordinates).

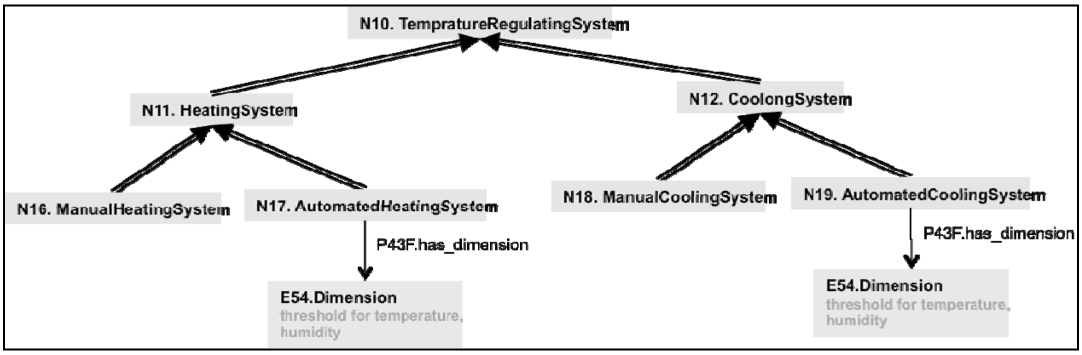

Figure 3. The analysis of the Temperature Regulating System of a building

As we discussed in section 2 we can also extend the model by using existing models that describe parts of our world that we do not want to re-describe ourselves. In our case a valuable addition is the ontology that describes the sensors, their measurements and the characteristics of the devices that conduct the measurements. Thus we can tap into the vast resources of sensors already described using this standard ontology (Compton et al. 2009, Compton et al. 2012). The main parts of this ontology follow (Fig. 4) and can be directly used with the proposed model.

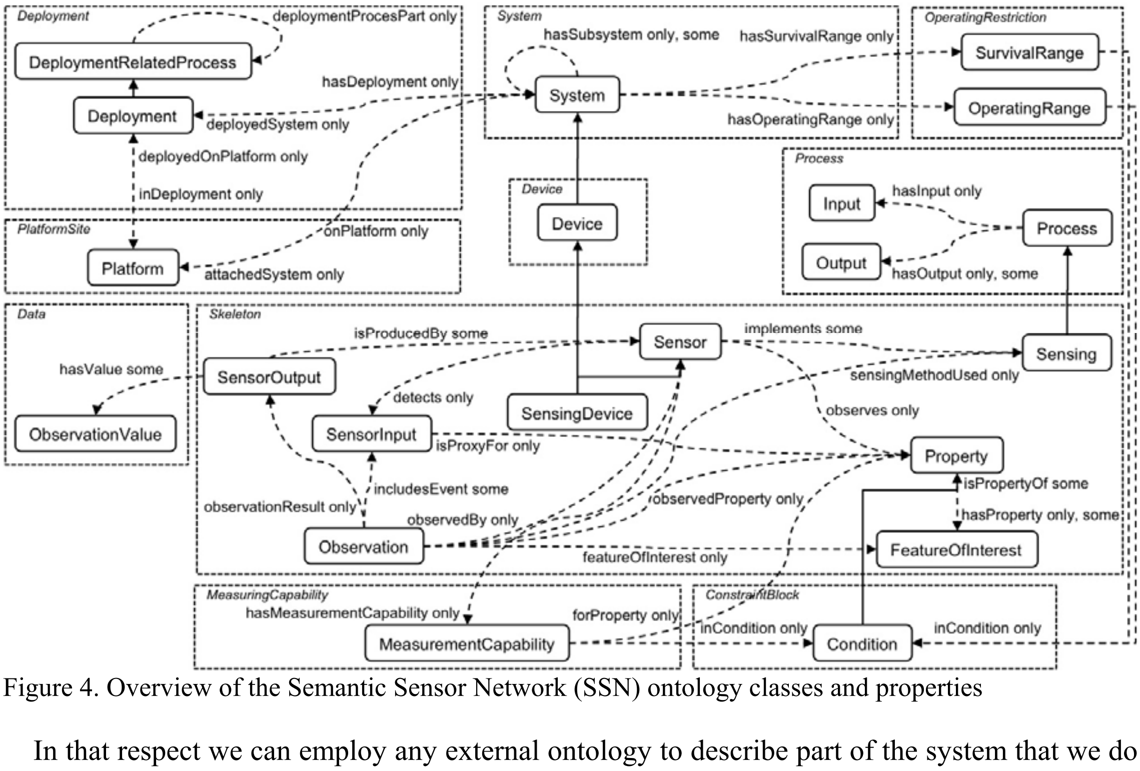

Figure 4. Overview of the Semantic Sensor Network (SSN) ontology classes and properties

In that respect we can employ any external ontology to describe part of the system that we do not want to describe ourselves or we cannot describe ourselves since no one can be an expert in various different fields. This way we guarantee better descriptions and better integration of the information being available from different sources throughout the information space.

4 CONCLUSIONS

In this work we proposed a conceptual model that captures all the required information related to a building's moisture profile and forms the basis for their storage, retrieval and exchange. Also, and given the correlation of the data related to a building's moisture profile with several aspects of building sustainability, the proposed model provides the possibility for unification with other building environmental performance- oriented models. The model can subsequently be used for doing more complex reasoning tasks on the provided information. This way, it contributes to the accomplishment of the difficult task of handling and integrating the plethora of information that have to be taken into account with regard to buildings' sustainability.

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Comparison of two sustainability assessment tools on a passive office in Flanders

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ABSTRACT: Last decade, different sustainability assessment tools have been developed to determine the sustainability level of buildings through a range of evaluation criteria. However, it often is unclear where these tools differ and how usable these tools are in practice. Therefore, two tools used in Flanders, BREEAM Offices and 'Assessment of office buildings'(AOB), developed by the Flemish government, have been applied to a passive office building. The evaluation process as well as the final score of both tools have been compared. The evaluation process appeared to be labour-intensive, thus creating a high threshold for these tools to be applied more commonly in practice, especially during the design phase. Furthermore, the comparison revealed that, in contrast of AOB, BREEAM informs not only on the quality of the building, but also on the management and use of it, resulting in more perspective for future improvement of the sustainability of both building and company.

1 INTRODUCTION

The last decades, a wide range of sustainability assessment tools has been developed worldwide. Aim of these tools is to determine in a quantitative and objective way the degree of sustainability of buildings by means of a set of evaluation criteria. Examples are the BREEAM schemes for different building types in the UK (also used outside the UK), LEED in the US, Green Star in Australia and CASBEE in Japan. More examples can be found in (Haapio & Viitaniemi, 2008) and (Forsberg & von Malmborg, 2004).

Many of these tools have been described in literature. As the overview in (Haapio & Viitaniemi, 2008) shows, most papers focus on the description and analysis of a particular tool, without comparing it with other tools. In case a comparison is made (Forsberg & von Malmborg, 2004, Shaviv, 2008), it is mostly on a theoretical basis by comparing the evaluated aspects, weighting factors, target group, etc. There are very few studies available where results of tools are compared for the same building. It, therefore, is not clear to which extent these tools, when applied to the same building, result in a similar score. In other words, how objective is the assessment of the sustainability level and to which extent does the rating depend on the tool used? Furthermore, also the usability of these tools in practice can be questioned, especially as support tool during the design phase of a sustainable building.

In this context two frequently used tools in Flanders have been compared, by applying them on an office building, built according to passive standard. The analyzed tools are the Dutch version of BREEAM for offices in use (BREEAM-NL BBG, 2012) as well as the tool 'Assessment of office buildings' (AOB, 2010), developed by the Flemish government. The aim was not to analyze the concepts and assumptions of these tools in detail on a theoretical basis, but to analyze the tools by using them for the assessment of a particular office building that has been designed as a sustainable, low energy building. Therefore, the evaluation process as well as the final score of both tools have been compared for this building.

Section 2 of this paper will present the office building and describe the measures that has been taken to create a passive/zero energy building. In section 3 the assessment concept of both tools will be presented as well as some aspects of the evaluation process. Section 4 and 5 will then present and discuss the main results. Finally, in section 6, conclusions are formulated.

2 CONCEPT OF THE BUILDING

The building is situated in the province of Limburg, Belgium, on a former mine site that has been redeveloped into a demonstration site for sustainable construction. The building is the office building of a company, active in energy efficient HVAC systems and solar energy systems. In view of its professional activities, the office had to be a demonstration of energy efficient technologies, with good indoor comfort during winter and summer and with minimized heating and cooling costs. In order to increase the level of sustainability, the building was built on this brownfield starting from an existing concrete skeleton that was left unfinished by another company. The building has a square ground floor and is 3 storeys high with an unheated/uncooled atrium over 2 storeys. Originally the building was conceived as a passive office building, but later on turned into a zero energy building through the installation of a large number of solar panels on both the roof and the façade. The ground floor contains a storage room, whereas office spaces are located on the first (figure 1) and second floor. The small offices are for the employees who stay in the office (figure 1), whereas an open-plan office on the second floor is used by the employees who often are on the road. Furthermore the second floor consists of a meeting room and a refectory.

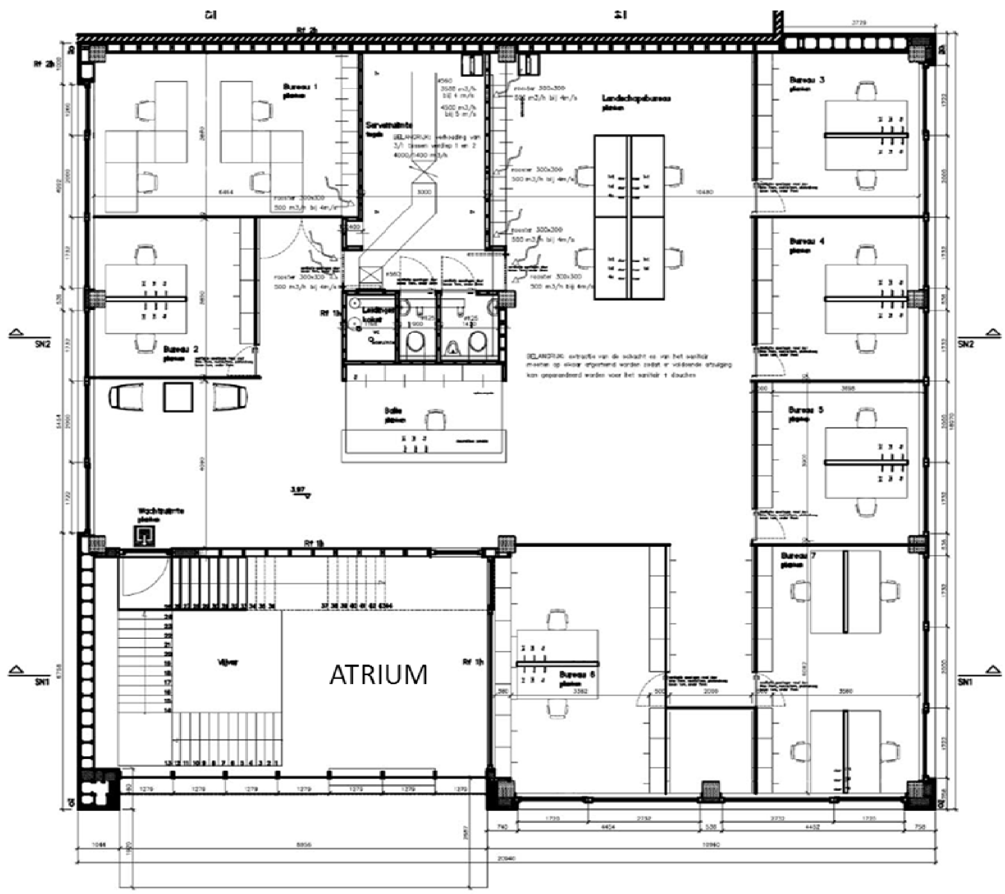

Figure 1. First floor of the office building.

A maximum of 40 employees are present simultaneously in the building. Table 1 presents the main characteristics of the building and the adopted technologies. Some of these are not installed yet. During the design phase, an analysis of the predicted summer comfort was made by a consultancy firm. Different scenarios for active cooling, night ventilation, ventilation rates and solar shading were tested with dynamic building simulations in order to determine the best solution for good summer comfort without high cooling costs.

Table 1. Characteristics of the building and adopted technologies.

	In use	Not installed yet
Building volume (m^3)	2500	
Heat loss area (m^2)	843	
Floor area (m^2)	606	
Glazing area (m^2)	112	
Compactness (m)	2.97	
U-value roof (W/m^2K)	0.13	
U-value façade (W/m^2K)	0.13-0.18	
U-value floor (W/m^2K)	0.20-0.31	
U-value windows (W/m^2K)	0.74	
Overall mean U-value (W/m^2K)	0.30	
Air tightness n50 (h^{-1})	0.54	
Mechanical ventilation with heat recovery and soil heat exchanger	X	
CO_2 and temperature sensor on ventilation		X
Heating- and cooling battery on ventilation system		X
Soil-water heat pump	12,9kW/COP=4.4	
Night ventilation	Manually controlled	Automatic control
Rain sensor for night ventilation control		X
Temperature sensor for night ventilation control		X
Solar shading	Manually controlled	Automatic control
Vacuum solar collector	8.25m²	
Solar panels on façade	5,76kWpeak	
Solar panels on roof	243,57kWpeak	
Rain water use	X	
Motion sensor to control indoor lighting	X	
Daylight sensor to control indoor lighting		X

With regard to sustainable material use, following choices were made: use of prefabricated wood frame components filled with cellulose insulation to cover the concrete skeleton, use of materials with low emissions of VOC's and formaldehyde (FSC-labeled and formaldehyde-free OSB), use of thermowood (thermally preserved softwood) and passive window frames made of softwood and cork.

Further sustainability related measures taken by the company concern rain water use (3 storage tanks of 10,000 liters each, connected to toilets and to some taps), an infiltration field for surplus rain water, water permeable parking lots, water saving toilets and dishwashing machine, no designed outdoor green space, only a grass-patch that is not mowed nor watered, waste sorting of wood, plastics, paper, cardboard, metals and solar panels, use of ecological cleaning products and energy efficient company cars, offering the possibility of flexible working hours and telecommuting and accessibility to public transport.

In 2011, the company was the winner of the Sustainable Construction Award for the most sustainable office building in Limburg. Unfortunately, the company went bankrupt very recently due to the economic crisis and abrupt changes in the financial support mechanisms for renewable energy by the Flemish government.

3 METHODOLOGY

3.1 *BREEAM-NL Offices in use*

BREEAM, which was originally developed by the British Building Research Establishment in 1998, is nowadays the most widely used sustainability assessment concept worldwide with country-specific versions for several countries. BREEAM-NL In Use is the version of the BREEAM In Use-International for offices, adapted to the Netherlands. This national scheme was developed by the Dutch Green Building Council with assistance of BREEAM. Since no specific BREEAM version exists for Flanders or Belgium, this Dutch scheme has been used within this research. For some aspects, such as the rating of the energy performance which is assessed in BREEAM-NL through the Dutch EPC score (i.e. the Dutch implementation of the EU

Energy Performance of Buildings Directive EPBD), the rating has been adapted by the researchers to the Flemish context (by means of the EPB score, the Flemish implementation of the EPBD which originally was inspired by the Dutch approach). Table 2 presents the evaluation themes and the weighting factor per theme. A particular aspect of the BREEAM schemes for buildings in use is that not only the building as such (asset) is assessed, but also the management and the use of building. The assessment of the asset takes into account the inherent performance aspects of the building, whereas the assessment of the management considers the management rules, procedures and plans regarding consumption of energy and water, waste management, etc. The assessment of the use of the building looks at the practices by and engagement of the employees as well as informational actions by the company towards to employees, with regard to sustainability.

Table 2. Evaluation themes and weighting factors for BREEAM-NL In Use.

Themes	Weighting factors		
	Asset	Management	Use
Management	0%	15%	12%
Materials	12%	7,5%	4,5%
Transport	9%	0%	18,5%
Waste	3%	0%	11,5%
Water	8%	5,5%	3,5%
Wellbeing and health	21%	15%	15%
Pollution	14%	13%	10,5%
Energy	25%	31,5%	19,5%
Land use and ecology	8%	12,5%	5%

Table 3 gives the score system with the rating benchmarks and the according number of stars. A score is given for asset, management and use separately.

Table 3. Score system of BREEAM-NL In Use.

Rating	Benchmark	Stars
Pass	25-39%	1
Good	40-54%	2
Very good	55-69%	3
Excellent	70-84%	4
Outstanding	≥85%	5

3.2 *Assessment of Office buildings*

Driven by the growing attention for sustainability, the Flemish government decided to develop a new sustainability assessment tool, specifically intended to assess its own building stock, named ‘Assessment of Office buildings’ (AOB). A first version appeared in 2007, focusing only on new office buildings, but since the update in 2010, the tool can be used for new, existing or renovated office buildings. For new constructions and renovations, the final score is mainly based on calculations and simulations of the design, whereas for a building in use, also measurements and monitoring are needed. The tool contains criteria for 3 major themes, representing each a maximum of 20 points: 1) quality of life and wellbeing, 2) energy and 3) environment and sustainability. Table 4 presents these themes with the underlying assessment categories and the maximum score per category. For energy, the evaluation is based on the calculation of the overall primary energy consumption according to the EPB (Flemish version of the EPBD). However, since the overall primary energy consumption alone is not a sufficient criterion to assess the energetic quality of the building, a system of vetoes is used, based on the calculation of the net heating demand, the energy losses by the heating system, the primary energy consumption for cooling, for lighting and for auxiliary systems (fans, pumps,…), also according to the EPB. The scores for these vetoes set a ceiling to the overall score for energy.

The final rating and the according number of stars are based on both the sub score per theme and the global score, calculated as the average of the 3 sub scores. This is shown in table 5. This way, a good final rating can be achieved only by having a good score for all three themes, thus avoiding that efforts would be focused on a selected group of sustainability aspects only.

Table 4. Evaluation themes and categories and maximum scores per category for AOB.

Theme	Category	Max. score
Quality of life and wellbeing	Accessibility	4/20
	Thermal comfort	4/20
	Acoustical comfort	3/20
	Vibrations	2/20
	Visual comfort	3/20
	Indoor air quality and ventilation	4/20
Energy	Level of primary energy consumption	20/20
Environment and sustainability	Location	3/20
	Facilities	3/20
	Durability	5/20
	Water use	3/20
	Material use	6/20

Table 5. Score system of AOB.

Rating	Score per theme	Overall score S	Stars
Narrow pass	None = 0	0 < S ≤ 1	1
Pass	None < 1	1 < S ≤ 2	2
Good	None < 2	2 < S ≤ 3	3
Excellent	None < 3	3 < S ≤ 4	4

3.3 *Evaluation process*

Tables 6 and 7 show in more detail for both tools the number of criteria to be assessed as well as the way the fulfillment of a criterion has to be proved, namely by means of measurements, calculations or documents (reports of studies, certificates, qualifications, presentations of workshops, minutes of meetings, policy plans, location plans, ….). Table 6 gives the criteria for AOB and table 7 for BREEAM-NL.

Table 6. Number of criteria to be assessed and means of verification for AOB.

Theme	Category	Number of criteria	Means of verification		
			measur.	calcul.	docum.
Quality of life and wellbeing					X
	Accessibility	1			X
	Thermal comfort	8	X		
	Acoustical comfort*	5	X		
	Vibrations*	1	X		X
	Visual comfort	14	X	X	X
	Indoor air quality and ventilation	3	X		
Energy					
	Primary energy consumption	6		X	
Environment and sustainability					
	Location	1		X	X
	Facilities	1			X
	Durability	1			X
	Water use	7			X
	Material use	11		X	X
	Total	59			

*Due to lack of appropriate monitoring equipment, these criteria could not been assessed.

The criteria of AOB on acoustical comfort and vibrations could not be assessed, due to the fact that no appropriate monitoring equipment was available. These criteria are marked with a * in table 6. The scores for these criteria were excluded and the calculation of the sub scores and the overall score was adapted. Since the maximum score that can be achieved for these criteria is 5/20 (see table 4), this resulted in a slightly lower weighting of the aspects of quality of life and wellbeing in the overall score than originally intended (15/55 instead of 20/60).

Table 7. Number of criteria to be assessed and means of verification for BREEAM-NL In Use.

Theme	Category	Number of criteria			Means of verification		
		asset	manag.	use	measur.	calcul.	docum.
Management	Project management	0	2	0			X
	Measuring and monitoring impact	0	2	7			X
	Integration of environment and accessibility	0	3	0			X
	Maintenance	0	2	0			X
Materials	Appropriate application	5	10	0			X
	Ecological materials	0	0	2			X
	Sustainably produced	0	0	4			X
Transport	Transport and mobility management	2	1	5			X
	Transport facilities	2	0	0			X
	Transport needs	0	0	2		X	
Waste	Recycling	1	0	2		X	X
	Reduction	0	0	2			X
	Management and monitoring	0	0	7			X
Water	Efficient use of drinking water	6	1	1	X	X	X
	Management of water consumption	1	0	4			X
	Use of alternative sources	8	1	0	X		X
	Measures against water wasting	3	1	0			X
Health	Visual comfort	5	1	0		X	X
	Indoor air quality	6	8	0	X		X
	Indoor temperature and humidity	2	1	0			X
	Acoustics	0	1	0	X		X
	Water quality	1	0	0	X		
	Safety and protection	1	2	2			X
Pollution	Local pollution of air, water and soil, noise or light pollution	11	9	5			X
	Pollution by refrigerants	3	0	0			X
Energy	Consumption due to systems and equipment	18	4	0	X	X	X
	Global consumption	12	7	0	X	X	X
	Consumption due to building geometry and material use	0	1	0			X
	Management of energy consumption	0	0	5	X	X	X
Landuse and ecology	Long term impact on biodiversity	3	1	0			X
	Reducing the disruption of biodiversity	2	4	0			X
	Total	92	62	48			

Measurements and calculations were executed by the researcher, as well as the observations that could be done through investigation of the available plans, an in-depth analysis of the building and surveys of the building users. Most documents had to be provided by the building manager. However, not all documents could be provided, some due to the fact that the related plans, reports or certificates were never established, others due to the fact that collecting the documents was considered too time-consuming by the building manager. Therefore, this information could not be included in the assessment.

4 RESULTS

Table 8 presents the ratings, based on the assessment with the BREEAM-NL In Use tool and table 9 the ratings for the assessment with the AOB tool. In the scores for the categories of BREEAM-NL, the weighting factors of table 2 have already been incorporated. More detailed results of the measurements, calculations and surveys can be found in (Verbeeck & Meex, 2013) and (Meex, 2013).

Table 8. Sub scores per category and final score for asset, management and use with BREEAM-NL.

Categories	Score		
	Asset	Management	Use
Management	0%	3%	3%
Materials	4%	4%	0%
Transport	1%	0%	2%
Waste	3%	0%	2%
Water	2%	4%	0%
Wellbeing and health	16%	7%	5%
Pollution	11%	12%	2%
Energy	23%	23%	6%
Land use and ecology	0%	0%	0%
Final score	61%	54%	20%
Number of stars	3	2	0

Table 9. Sub scores per theme and final score with AOB.

Theme	Score	Number of stars
Quality of life and wellbeing	2,1/4	3
Energy	3,2/4	4
Environment and sustainability	2,2/4	3
Final score	2,5/4	3

5 DISCUSSION

As can be concluded from the description of the tools in section 2, the tools contain both similar and divergent categories and criteria. Energy is the most important theme in both tools and has a considerable weight: one third of all points can be achieved through energy aspects in AOB and the weighting factors for energy in BREEAM-NL are 19,5% to 31,5%, depending on the focus. Wellbeing and health is the second most important group of criteria in both tools, with once again one third of all points in AOB and a weighting factor of 15% to 21% in BREEAM-NL. However, one should be beware of the fact that a similar category name does not necessarily mean similar assessment criteria. This makes an in-depth comparison of the tools very difficult and this was not the aim of the research.

More important for the research was to deduce the underlying concept of both tools and this can be found through the analysis of the differences. A large difference between both tools is the fact that the AOB tool only assesses the performance of the building as such, whereas BREEAM-NL In Use makes a distinct assessment of the building, the management of the building and the use of the building. Another distinction is that the assessment of BREEAM is much more based on the presence of policy plans, reports of studies, certificates, technical documentation, etc. to prove the degree of sustainability, whereas the assessment of AOB is much more based on measurements and calculations of actual performances. This reveals a quite large difference in scope between both tools, which is also confirmed by the differences in categories and the number of criteria to be assessed. BREEAM-NL has a much wider scope on sustainability, not only in time (as it also considers ongoing processes of information, control and interaction during the use phase of the building), but also with regard to the considered aspects. Aspects such as land use, biodiversity and transport and mobility are not or only to a very small extent included in AOB.

These similarities and differences are also reflected in the ratings. Although both tools have a different weighting system, the building as such has a similar rating in both tools: a score of 61% in BREEAM-NL and 2,5/4 (=62%) in AOB, resulting in 3 stars in both tools (the maximum number of stars is 5 in BREEAM-NL and 4 in AOB). From these results, it can be concluded that the asset is assessed as a good (AOB) to very good (BREEAM) building with regard to its degree of sustainability. At this point, both tools seem to come to an equivalent evaluation. The management and the use of the building however have only be assessed in BREEAM and the results are less positive. For the management, still a score of 54% (2 stars) is achieved, mainly due to a good score for energy and for pollution. For the use of the building, reflecting the engagement of the employees and the information policy of the company, the score is quite low. The highest scores there are achieved for energy (6%) and for wellbeing and health (5%). This clearly reflects the reality of the company where much effort has been made to optimize the energy efficiency and the indoor climate of the building, but much less effort in informing the employees on the functioning of the passive building and the way to interact with the building (use of lighting, opening of windows, role of night ventilation). Other aspects such as use of ecological materials and waste sorting were a focus during the design and construction phase, but less attention has been paid to these aspects afterwards. During the use of the building, cost and quality became the most important criteria when choosing suppliers and sustainable production was not considered anymore. For waste sorting, this remained adopted during the use phase, but no attention was paid to waste quantities or the destination and treatment of the waste after leaving the company. The BREEAM assessment also revealed that there still are aspects that never have been considered by the company such as biodiversity and informing the employees on the functioning and performance of the building. This shows that the BREEAM assessment, apart from giving a label, can also play a informative and sensitizing role.

With regard to the evaluation process, the application of both tools appeared to be a very time-consuming process. For BREEAM, 220 questions had to be answered and for AOB 59. Many of these questions could not be answered easily, but required monitoring actions during some weeks up to a year, energy calculations and collection and analysis of a huge amount of documents in preparation of the assessment. Once this information was available, filling in the check list was not difficult, neither for BREEAM nor for AOB. Positively, BREEAM has also some simple calculations tools available for the assessment of some of its criteria (average building age, combined CO_2 emissions of the building). Furthermore, BREEAM has, in general, also more answering options per criterion than AOB, often resulting in a more balanced answer to the criterion. But in its current form, none of these tools can be used by architects during the design phase, as it is too prescriptive and deterministic to be useful for a designer.

6 CONCLUSIONS

The application of the two most widely used tools in Flanders on the same passive building together with the comparison of the results and the evaluation process revealed some interesting information on the strengths and weaknesses of these tools. Positively, both tools gave a comparable rating of the building as such, but obviously, based on 1 test, this cannot be generalized. What can be concluded is that none of the tools is well conceived in its current form to serve as a design support tool, as they are both deterministic checklists with a large number of criteria and very time-consuming to fill in. However, with regard to the assessment of the sustainability level of an existing building, BREEAM-NL In Use appeared to be much more informative for the building manager than AOB as the results clearly reveal the weak points in the sustainability policy of a company and can therefore serve as a source for suggestions for further improvement.

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Spatial Quality Assessments for Building Performance Tools in Energy Renovation

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ABSTRACT: This study explores existing technology that has the potential to assess defined spatial quality parameters. This paper focuses on the parameters of *views, isolation* and *contact.* The goal of this research is to develop indicators that best assess spatial quality. Suitable indicators enable the implementation of spatial quality assessment in building performance assessment tools. Examples of good indicators for *views, isolation* and *contact* consider visual openness and visual privacy to assess view quality. In future research, the spatial quality indicators developed here will be applied to case studies in the European context. Once they have been established, the indicators can be implemented in the building performance tool SBTool to improve spatial quality assessment in energy renovation. Improved spatial quality is one argument that provides stakeholders with justification for increasing investments in energy renovation because it contributes to individuals' well-being.

1 DEFINITION OF SPATIAL QUALITY

1.1 *Spatial Quality Parameters*

The existing literature shows that spatial quality is difficult to define because it embraces diverse features of various natures. The term is among the core concepts in urban planning and policy (Moulaert 2011). However, the definition of spatial quality needs to be reduced to the scale of the building because spatial interventions at the urban macro scale affect the micro scale of the building considerably. The work of Rapoport (1994a) set the departure point of the literature study. Several authors, including Alexander and Ishikawa (1978), Ashihara (1981), Gehl (2010, 2011), Lynch (1960), Moulaert (2011) and Weber (1995), also contributed to the definition of spatial quality. The boundaries of the study of spatial quality were defined through parameters, that define a system or sets the conditions of its operation (Oxford Dictionary). Thus, the range of definitions for spatial quality is bounded by the parameters defined according to the literature study.

In addition to the literature study on the definition of spatial quality, energy measures used in building renovation were also analysed. The goal was to define the spatial quality parameters that are most impacted by energy renovation. The following spatial quality parameters were defined according to the literature study: *views, isolation, contact, internal and external spatial arrangements, transition between public, semi-public, semi-private and private spaces, and perceived and built densities* (Pacheco 2013a). This paper concentrates on the *views, isolation* and *contact* parameters. These parameters are represented by visual openness and visual privacy and are affected by distance and the viewing angle (Gehl 2010, Indraprastha 2012). The possibility of encounters and visual interaction varies considerably according to the body distance and viewing angle.

2 SPATIAL QUALITY ASSESSMENT

2.1 *Spatial quality parameters, energy renovation and the building performance tool SBTool*

This paper focuses on the relation among the *views, isolation* and *contact* parameters for spatial quality and the energy renovation measures that consider the walls and windows of a building. The energy renovation measure of *changing the glazing distribution by new apertures* (Barker 2009) can exemplify the types of relations proposed. The aperture of the window and its placement in the façade are adjusted to improve the distribution of daylight (Barker 2009). The daylight distribution affects the *views, isolation* and *contact* parameters because it influences the visual openness and visual privacy of the building (Pacheco 2013a, b).

The SBTool Generic System (version 2012) building performance tool is considered for the analyses of the spatial quality indicators. The tool is "a generic framework for building performance assessment that may be used by third parties to develop rating systems that are relevant for a variety of local conditions and building types" (Larsson 2012). Despite its generality, "the SBTool is based on the philosophy that a rating system must be adapted to local conditions before its results can become meaningful" (Larsson 2012). We worked with the complete "developer version" of SBTool, which considers all of the criteria to be used by the core project team. The SBTool performs assessments through *focused variants*. The indicators considered related to spatial quality belong to the variant *Social and Perceptual Issues*.

2.2 *Definition of Indicators*

One of the main goals of this study is to develop spatial quality indicators at the building scale. The objective is to improve the assessment of spatial quality using the building performance tool SBTool. Thus, an indicator needs to be defined according to reliable literature.

The international standard ISO21929-1 (2011) states that an indicator has three main functions: quantify, simplify and communicate. Indicators can be used to define goals, monitor changes and illustrate a tendency. According to the World Health Organization (WHO), an indicator has the following scientific characteristics:

Validity: the indicator measures what it is possible to measure;

Reliability: the assessment provides similar results when repeated by different observers;

Sensitivity: the indicator is able to recognise changes; and

Specificity: the indicator reflects changes in specific circumstances.

The outcomes of the assessment given by indicators are not perfect; indicators provide an approximation of an actual situation. Thus, indicators are useful for assessments because no positive or negative values are associated with the outcomes. The aggregation of value results from the interpretation and analysis of these outcomes.

2.3 *Spatial Quality Indicators in the Building Performance SBTool*

The SBTool has two indicators for assessing the spatial quality parameters of *views, isolation* and *contact.* Both indicators belong to the Social, Cultural and Perceptual Aspects category (F):

SBTool F1.3 – "Visual privacy in principal areas of dwelling units. Indicator: The percentage of dwelling units whose bedroom and living areas are open to horizontal or downward views from a point within 20 m of the exterior windows" (Larsson 2012); and

SBTool F3.7 – "Access to exterior views from interior. Indicator: Visual quality of exterior artefacts or natural objects and their distance from the viewer" (Larsson 2012).

SBTool F1.3 belongs to the Social Aspects criterion (F1), and SBTool F3.7 belongs to the Perceptual Aspects criterion (F3).

The energy renovation measure of *changing the glazing distribution by new apertures* (Barker 2009) exemplifies the potential for using these indicators (SBTool F3.7 and F1.3) to assess spatial quality. This renovation measure affects the *views, isolation* and *contact* parameters because it influences the visual openness (or visual contact) and thus the level of privacy (Rapoport 1994b, Gehl 2010). Visual openness in terms of visual contact and privacy is the main focus of these SBTool spatial quality indicators. Thus, these indicators have the potential to evaluate the effect of *changing the glazing distribution by new apertures* on the *views, isolation and contact* parameters (Pacheco 2013b).

The indicators analysed here primarily offer recommendations rather than a reliable assessment of spatial quality. Definitions are lacking, and the assessment relies on individual interpretations. These SBTool indicators do not follow the scientific characteristics required to be considered real indicators (section 2.2). However, the analysis illustrates the potential for using the SBTool to assess spatial quality.

This paper explores the existing spatial quality assessments for improving SBTool indicators F1.3 and F3.7. This exploration is presented in section 3. Visual openness and visual privacy are the main focus of both indicators. Therefore, further research on ways to assess these issues is required. Furthermore, the indicators do not define the terms "visual quality of external views" and "privacy levels", which constitute the backbone of the assessment proposed by these indicators.

3 EXPLORATION OF SPATIAL QUALITY ASSESSMENTS ON VISUAL OPENNESS AND VISUAL PRIVACY

3.1 *Potential of spatial mapping and 3D modelling*

The spatial quality indicator to be developed focuses on assessing the spatial quality parameters of *views, isolation* and *contact* (section 1.1). The issues of concern are visual openness and visual privacy, both of which are assessed in two approaches, following the mapping model proposed by Indraprastha (2012). The first approach considers the visual distance (in meters), and the second approach considers the viewing angle. Indraprastha's (2012) mapping model evaluates visual openness and visual quality through a mathematical approach (see the appendix). The model starts by defining the geometrical centre point of a room. A Cartesian grid is proposed, with its origin at this centre point. Then, the edges of the apertures of doors and windows are projected perpendicular to both the vertical (y) and horizontal (x) axial lines. The space is subdivided in enclosed spaces according to the projections on the x and y axial lines. The geometrical centre point of each enclosed space is determined and numbered (figure 1).

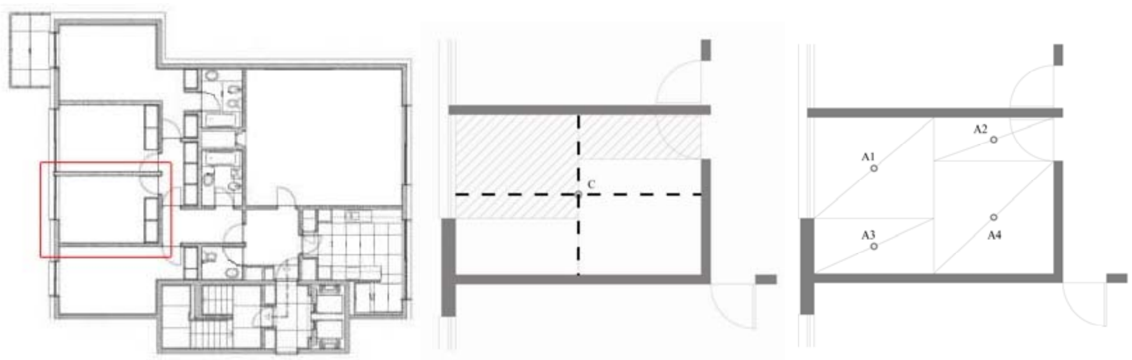

Figure 1. Boa Vista House, architect: Alvaro Siza, Porto, Portugal. Subdivision of a sleeping room in enclosed spaces and placement of the geometrical centre point *A* of each enclosed space considering the projection of the openings (door and window) on the vertical axial line *y*

Centricity is among the *principles of figural segregation* defined by Weber (1995). Considering the relevance of the concept of centricity in Indraprastha's model (2012), centricity is the only figural segregation principle considered here. According to Weber (1995), space is perceived "both as the corporeality of physical objects and the shape of the void these objects create". The architectural space is "the void between walls and buildings" that "can assume the quality of a perceptual figure" (Weber 1995). Weber defines and exemplifies the shape of the void in the *principles of figural segregation* considering three-dimensionality. The author refers to these principles as only applicable to "*clearly defined spaces*", which possess the figural character of an enclosed shape with subordinate boundaries. According to Weber (1995), *centricity* is not necessarily the geometrical centre of a shape, but it is the perceptual centre. The perceptual centre considers the dynamics of the interaction between the subordinate boundaries of a shape (walls) and the openings (windows and doors).

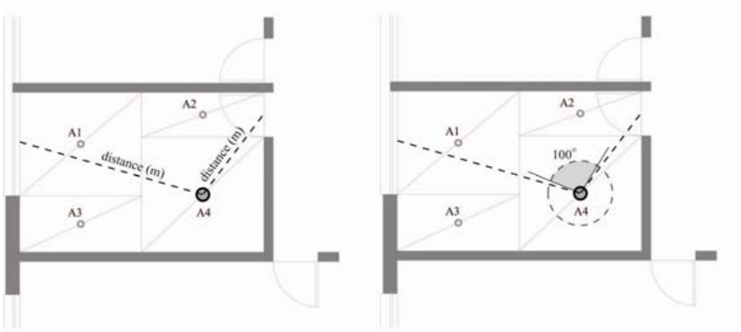

Figure 2. Boa Vista House, architect: Alvaro Siza, Porto, Portugal. Distance (m) and maximum viewing angle of 100° between the geometrical centre point *A4* of the enclosed space to the midpoint of the openings.

The assessment of the spatial quality issues of visual openness and visual privacy follows Indraprastha's mathematical approach (2012), which is presented in the appendix of this paper.

Visual openness. Three variables are defined to calculate visual openness (see the appendix):

- Visual distance: the distance between the geometrical centre point *p* of an enclosed space and the midpoint of the openings (doors and windows).
- Transparency ratio: the ratio between the area of the openings and the area of the wall where the opening is placed.
- Viewing area: the ratio of the viewing area from the geometrical centre point *p* of an enclosed space, considering a maximum viewing area of 100°.

Visual privacy. The calculation of visual privacy considers two distinct methods: the average value of privacy both by distance and by viewing area. In the method of calculating privacy by distance, the distance from a point *p* to the opening determines the level of privacy. The method of calculating privacy by viewing area considers how many windows and doors are covered by the viewing angle, where the privacy is lower if more openings are covered (a geometrical centre point *p* is more visible from outside when the viewing angle covers many openings) (see figures 1 and 2 and the appendix).

In the Indraprastha model (2012), the results of the analysis are interpreted as follows:

- Visual openness index: the visual openness index decreases with an increasing average distance from a geometrical centre point *p* to the windows and increases with an increasing viewing angle at *p* covering all of the windows.
- Visual privacy index: the visual privacy index increases with an increasing average distance from a geometrical centre point *p* to the windows and doors and decreases with an increasing viewing angle at *p* covering all of the windows and doors.

The visual openness and visual privacy indexes are calculated for each enclosed space: "the term visual openness index refers to the level of visual influence at a center point *p* of a subdivided enclosed space", and visual privacy refers to the presence of a point *p* in bounded area as "a result of being viewed from external spaces" (Indraprastha 2012).

In the proposed method, the results of both approaches (the visual distance and viewing angle) are combined to obtain an average weight of visual openness and visual privacy. The average is found for the geometrical centre point *p* of each enclosed space (figures 1 and 2). The result can be used to both explore design alternatives and analyse the impact of design changes.

4 RESULTS

This section presents a short summary of the potential technology and literature on spatial quality reviewed in this research. Some of the current technologies for assessing the spatial quality parameters of *views, isolation, and contact* are presented below.

The Indraprastha (2012) model is integrated as part of the spatial quality assessment. The assessment consists of spatial quality indicators, which are developed and integrated into the building performance tool SBTool. The model is expected to contribute to the assessment of the impact of energy renovation on spatial quality parameters (section 1.1). The Indraprastha (2012)

CAD-based mapping model analyses the interior spaces with accurate computer simulation. However, the model has limitations. According to Indraprastha (2012) the model does not consider the height of the ceiling. In addition, the restriction of analysing visual openness and visual privacy considering only the interior spaces is a potential topic for future research (section 5).

Indraprastha (2012) considers the openings (windows and doors) to be highly influential on the visual openness and privacy assessments: “spatial quality evaluation depends on the layout configuration of the openings that made up the spatial mapping as we developed”. The main contribution of the Indraprastha (2012) model to spatial quality assessments is the distribution of the openings’ influence to each enclosed space considering their location in the room. Furthermore, the method is efficient in defining the geometrical centres of the enclosed spaces, thus allowing the analysis to obtain reliable results more quickly than when implementing, for example, a raster method.

The concept of centricity presented by Indraprastha (1995) corresponds with Weber’s (1995) *principles of the figural segregation of centricity*. Centricity is related to the centre of a shape (Weber 1995). Nevertheless, the centre is not necessarily the geometrical centre of a shape but rather the perceptual centre. Such a centre is defined by the convergence of forces resulting from the entire organisation of the shape and the articulation with its boundaries. A shape may have many sub-centres, but the shape is clearer if it has fewer sub-centres (Weber 1995). Indraprastha's model (2012) considers the forces resulting from the entire organisation of the shape and its boundaries by defining the geometrical centres of each enclosed space and by distributing the openings’ influence to these enclosed (sub-)spaces both geometrically and mathematically (figure 1).

Assessments of spatial quality assessment at the building scale extend beyond the building scale self (Weber 1995). Weber (1995) emphasises the impact of larger-scale elements on the perception of the space of single entities. His considerations are an inspiring departure point for developing spatial quality assessments. Indraprastha's (2012) CAD-based mapping model analyses only the interior spaces. Thus, any influence of the immediate exterior space in the interior space is not considered in the analyses of visual openness or visual privacy.

5 CONCLUSIONS AND FUTURE WORK

A spatial quality assessment is being developed in the research to which this paper belongs. Visual openness and visual privacy are among the topics considered using the proposed spatial quality parameters (section 1.1). Spatial quality indicators for both visual openness and visual privacy will be developed. These indicators can be used with the building performance tool SBTool to assess the impact of the energy renovation measures on spatial quality, such as the impact of the energy renovation measure of *reduction of aperture area* on the spatial quality parameters of *views, isolation* and *contact* (section 2.1). This impact will be analysed considering the impacts of energy renovations. The indicator can also be used to explore refurbishment alternatives considering their impact on spatial quality.

Weber's *principles of figural segregation* (1995) will contribute to the analysis of the results of the spatial quality assessment to be developed by future research.

A review of the literature on the definition of spatial quality shaped our needs and priorities in developing a spatial quality assessment. From this review, we identified both the potential and need to complement the Indraprastha model (2012). Following Weber’s (1995) consideration that spatial quality assessment at the building scale extends beyond the building scale self, the Indraprastha model (2012) needs to be extended to include the immediate exterior space adjacent to the external boundaries. The inclusion of the exterior space enables a complete assessment in terms of the analysis of visual openness and visual privacy. Ways of providing visual and systematic spatial quality analysis that are able to connect with and complement the Indraprastha model (2012) will be explored, and spatial quality indicators will be proposed.

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APPENDIX

The procedures for measuring the visual openness and visual privacy indexes for each geometrical centre point *p* are explained below in seven steps (Indraprastha 2012).

– VO: Visual openness

1. Calculate the average distance (D) between point *p* and the windows:

$$D_{p}^{-vo} = \frac{\sum_{i=1}^{n} dW_{ip}^{vo}}{n} \tag{1}$$

2. Calculate the visual openness strength of influence at point *p* using the distance method:

$$VO_{p}^{-} = Exp\frac{-D_{p}^{-vo2}}{D_{p}^{-vo}} \tag{2}$$

3. Calculate the visual openness level using the distance method considering the transparency index of the window:

$$VO_{\bar{D}p} = VO_{\bar{D}p}(tr) \tag{3}$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{vo} = \frac{\theta_p}{100^{\circ}} \tag{4}$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$VO_{\omega_p} = Exp\frac{\omega_p^{vo2}}{\omega_p^{vo}} \tag{5}$$

6. Normalise the VO level (3) and strength of influence values (5).

7. Combine the VO level (3) and strength of influence values (5) to obtain the arithmetic average:

$$VO_p = \frac{1}{2}(VO_{\bar{D}p} + VO_{\omega_p}) \tag{6}$$

- PR: Visual privacy

  1. Calculate the average distance (D) between point *p* and the windows and doors:

$$\bar{D}_p^{pr} = \frac{\sum_{i=1}^{k} dD_{ip}^{pr}}{k} \oplus \frac{\sum_{i=1}^{n} dW_{ip}^{pr}}{n} \tag{7}$$

2. Calculate the visual privacy strength of influence at point *p* using the distance method:

$$PR_p = Exp\frac{\bar{D}_p^{pr2}}{\bar{D}_p^{pr}} \tag{8}$$

3. Calculate the visual privacy level using the distance method, considering the transparency index of the window:

$$PR_{\bar{D}p} = PR_{\bar{D}p}(\bar{tr}) \tag{9}$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{pr} = \frac{\theta_p}{100^{\circ}} \tag{4}$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$PR_{\omega_p} = Exp\frac{-\omega_p^{pr2}}{\omega_p^{pr}} \tag{10}$$

6. Normalise the PR level (3) and strength of influence values (5).

7. Combine the PR level (3) and strength of influence values (5) to obtain the arithmetic average:

$$PR_p = \frac{1}{2}(PR_{\overline{D}p} + PR_{\omega_p}) \qquad (11)$$

where
dW_p = distance from the geometrical centre point *p* to the midpoint of the window;
dD_p = distance from the geometrical centre point *p* to the midpoint of the door;
aW_i = area of window i; aW_{Li} = area of the wall where window i is placed;
aD_i = area of door i; aW_{Di} = area of the wall where door i is placed;
n = number of windows; k = number of doors;
$tr_{wi} = (aW_i / aW_{Li})$ = transparency index of window i;
$tr_{di} = (aD_i / aW_{Di})$ = transparency index of door i;
θ^{vo} = visual angle at the geometrical centre point *p* having all windows covered;
ω^{vo} = visual openness ratio of the covered angle;
θ^{pr} = visual angle at the geometrical centre point *p* having all windows and doors covered;
ω^{pr} = privacy ratio of the covered angle;

AQUA certification system and the design of buildings

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ABSTRACT: The construction industry causes great environmental impact by using natural raw materials and delivering products that generate a lot of waste. In order to assess the environmental conditions of buildings, several certification systems are used abroad, and some of them have been adapted to Brazil. This paper aims to describe the Brazilian system AQUA (for office and educational buildings) and analyze its Categories 1 and 7 since the requirements of these categories are more closely related to the way buildings are designed. This system is an adaptation of the *'Haute Qualité Environnementale - HQE'* system for Brazil. The research method included a case study conducted at a newly-constructed building of a federal institution. Results show that concern with environmental issues in the design stage is still incipient. However, a number of recommendations could be made in order to contribute to the development of new projects of this institution.

1 INTRODUCTION

In recent decades, discussion on environmental protection combined with sustainable development has increased . According to Sattler (2001), concern with sustainable development arose after the occurrence of social problems, environmental degradation and shortage of resources due to the need to offer species (including the human species) a higher quality of life.

In Brazil, this topic gained more prominence in 1992 during the United Nations Conference on Environment and Development (ECO 92), held in Rio de Janeiro, where a consensus was reached among the various participating nations that strategies for sustainable development should consider environmental aspects integrated with development plans and policies (Silva, 2003).

The construction industry is part of this context. This industry has been touted as one of the sectors most responsible for environmental impacts, due to its use of non-renewable, natural raw materials, as well as for creating waste-generating products that often require aggressive adaptation on the sites where they are built (Tobias & Vavaroutos, 2009). According to the Department of Environmental Issues for the State of Sao Paulo (2010), this industry accounts for up to 40% of global CO_2 emissions and, in Brazil, it accounts for the use of 21% of treated water, 42% of all energy generated, and about 60% of the waste produced.

Certification systems emerged in an attempt to transform the construction industry according to sustainable concepts, and due to the lack of regulations that could guide and manage activities in the industry in a more responsible manner (Mendler, 2006). These systems thoroughly evaluate requirements in order to encourage and maintain sustainable practices among owners, users and operators, and reduce environmental impacts throughout the life cycle of a building (Lamberts et al. 2010).

Performance evaluation supported by certification provides new, similar developments to the project, with the ability to diagnose and indicate where improvements are needed in order to achieve greater process, system, and material efficiency, for example. Thus, based on evaluations, it is possible to check the necessary requirements and those which can be further improved (Lamberts et al. 2010).

However, in the case of public works this discussion requires the consideration of some specific aspects due to certain limitations of this type of project in comparison to private works. In Brazil, public works are subject to the Bid Law 8.666 whereby an agreement is only signed after a bidding process is completed in which the company that submits the lowest price wins the bid (Brasil, 1993).

On the other hand, the creation of the Support Program for the Restructuring and Expansion of Federal Universities (REUNI) has transformed public universities into construction sites. This program was created by the federal government in order to increase higher education access and retention (MEC, 2011).

Based on these facts, this paper aims to describe the Brazilian AQUA certification system and analyze Categories 1 and 7 from among fourteen categories, since these are directly related to the way buildings are designed, in order to help improve new educational building projects at the Universidade Federal de Juiz de Fora (UFJF), a participating member of REUNI which is currently under a rapid expansion process

2 THE AQUA CERTIFICATION SYSTEM - HIGH ENVIRONMENTAL QUALITY

AQUA can be defined as a project management process to achieve environmental quality for new or renovated developments, and can be applied during the building design, creation, or construction stage (Fundação Vanzolin, 2007).

AQUA was published in Brazil in October 2007 as a result of the translation and adaptation of the French HQE (*Haute Qualité Environnementale*). This work was developed by Fundação Vanzolin under a cooperation agreement with Certivéa, responsible for preparing the Referentiel Technique de Certification *"Bâtiments Tertiaires - Démarche HQE"*, which helped create a Technical Reference (TR) for Certification for offices and educational buildings. This reference was structured into two instruments: a reference for the Project Management System (PMS) to assess the environmental management system and a reference for the Environmental Quality of Buildings (EQB) to assess the architectural and technical performance of construction.

The EQB is divided into four families encompassing fourteen categories that are further divided into subcategories which, in turn, are broken down into 120 concerns related to environmental challenges. Each concern is represented by one or more indicators, and performance assessment follows both qualitative criteria, based on the description of the measures adopted ('requirement met' or 'requirement not met'), and quantitative criteria, based on assessment methods, measurements and estimates (good, high standard or excellent).

For the "Comfort" families, under the "Sanitary Quality of the Air" and "Environmental Sanitary Quality" categories, parameters to achieve certification change depending on the different buildings. Currently, there are different technical certification references for "Offices and Educational Buildings", "Hotels" and "Residential Buildings." The relationship between families and categories are shown in Table 1.

2.1 *Category 1 - Relationship between Buildings and Their Surroundings*

This category addresses how a project development considers data from previous analyses of its deployment site, and the impact it causes on the environment in terms of community and neighbors.

This category also addresses the impact of comfort and health of outdoor spaces of the project on the users of the land: outdoor environmental comfort, outdoor acoustic comfort, outdoor visual comfort, and healthy outdoor spaces. Category 1 subcategories and concerns are shown in Table 2.

Table 1. Families and categories of EQB

Families	Categories
Green-building	1. Relationship between Buildings and Their Surroundings 2. Integrated Choice of Products, Systems and Building Processes 3. Low Environmental Impact Construction Site
Management	4. Energy Management 5. Water Management 6. Use and Operation Management of Buildings 7. Maintenance - Continuity of Environmental Performance
Comfort	8. Hygrothermal Comfort 9. Acoustic Comfort 10. Visual Comfort 11. Olfactory Comfort
Health	12. Environmental Sanitary Quality 13. Sanitary Quality of the Air 14. Sanitary Quality of the Water

Table 2. Category 1 - Relationship between Buildings and Their Surroundings.

Subcategory		Concerns	
1.1	Implementing a project development on-site for a sustainable urban development	1.1.1	Ensuring consistency between implementation of a project development on-site and the community policy in terms of land arrangement and territorial sustainable development
		1.1.2	Managing means of transportation and encouraging those less polluting
		1.1.3	Preserving the ecosystem and biodiversity
		1.1.4	Preventing the risk of flooding in susceptible areas and limiting the spread of pollutants
1.2	Quality of outdoor spaces for users	1.2.1	Creating suitable outdoor environment comfort
		1.2.2	Creating suitable outdoor acoustic comfort
		1.2.3	Creating suitable visual comfort
		1.2.4	Ensuring healthy outdoor spaces
1.3	Impacts of a building on the neighborhood	1.3.1	Ensuring the neighborhood's right to sunlight
		1.3.2	Ensuring the neighborhood's right to bright light
		1.3.3	Ensuring the neighborhood's right to views
		1.3.4	Ensuring the neighborhood's right to health
		1.3.5	Ensuring the neighborhood's right to peace

2.2 *Category 7 - Maintenance - Continuity of Environmental Performance*

This category is directly related to conservation and maintenance actions to ensure those efforts that have already been undertaken in other categories. According to the TR, good maintenance is identified by the following qualities: "optimized maintenance needs; low environmental and sanitary impact of the products and procedures used; guaranteed execution in all situations; monitoring methods that allow continuity of performance; access to equipment and systems," (Fundação Vanzolin, 2007).

Thus, technical provisions to maintain environmental performance are concentrated and divided into three concerns: availability of means to monitor and control performance; simplicity of design and limitation of disturbance caused to occupants due to malfunction or preventive or systematic operation for conservation/maintenance; and easy access, to guarantee appropriate cleaning/conservation/maintenance. Category 7 subcategories and concerns are shown in Table 3.

3 RESEARCH METHODOLOGY

Research begins with a literature review on the subject focusing on the Brazilian AQUA system, followed by a case study. The research methodology can then be classified as descriptive, with a qualitative nature, based on a case study strategy.

A data collection document was created containing 353 questions that include the fourteen categories of the system based on the TR for Certification, Service Industry Buildings, AQUA Process for Offices/Educational Buildings (Fundação Vanzolin, 2007). These questions refer to measures that should be taken to meet the AQUA system requisites, and came from the concerns and examples of measures as presented in the reference for each of its subcategories.

The recently built Engineering School facility of the UFJF. Data was collected through on-site visits, document analyses, interviews with the project company which won the bidding process (responsible for the architectural design and hiring of complementary projects) and UFJF's infrastructure department. The completed questionnaire with all of the responses can be found in Caldeira (2013), while this article includes the responses to Category 1 (Relationship between Buildings and Their Surroundings) and Category 7 (Maintenance - Continuity of Environmental Performance). Sample questions are shown in Table 4 for the 7.1.3 concern.

Table 3 - Category 7 - Maintenance - Continuity of Environmental Performance

Subcategory		Concerns	
7.1	Continuity of heating and cooling system performance	7.1.1	Providing the necessary means to monitor and control performance during use and operation of the building
		7.1.2	Ensuring simplicity of design for easy maintenance and limited disturbance caused to occupants during maintenance interventions
		7.1.3	Designing the building for easy access for conservation/maintenance interventions during use and operation
7.2	Continuity of ventilation system performance	7.2.1	Providing the necessary means to monitor and control performance during use and operation of the building
		7.2.2	Ensuring simplicity of design for easy maintenance and limited disturbance caused to occupants during maintenance interventions
		7.2.3	Designing the building for easy access for conservation/maintenance interventions during use and operation
7.3	Continuity of lighting system performance	7.3.1	Providing the necessary means to monitor and control performance during use and operation of the building
		7.3.2	Ensuring simplicity of design for easy maintenance and limited disturbance caused to occupants during maintenance interventions
		7.3.3	Designing the building for easy access for conservation/maintenance interventions during use and operation
7.4	Continuity of water management system performance	7.4.1	Providing the necessary means to monitor and control performance during use and operation of the building
		7.4.2	Ensuring simplicity of design for easy maintenance and limited disturbance caused to occupants during maintenance interventions
		7.4.3	Designing the building for easy access for conservation/maintenance interventions during use and operation

Table 4 - Concern 7.1.3 - Designing the building for easy access for conservation/maintenance interventions during use and operation

Was accessibility to different elements of the heating and cooling system provided, including air intakes?
Were points of access sized so as to allow for the replacement of large elements such as boilers or air conditioning central systems?
Were intervention zones sized accordingly around the equipment?
Are there lighting and power feeding points where conservation/maintenance practices are to take place?

Answers were classified as "Yes" if requirements were met; "No" if requirements were not met; and "Partially" if a requirement did not completely meet a criterion. Additionally, some requirements were considered "Not applicable" in cases where they did not correspond to the configuration of the project under consideration.

4 RESULTS AND ANALYSIS

The construction of new buildings at UFJF needs to follow the provisions in the Institution's Master Plan, and because these works are public, they must undergo a bidding process. The work in question was entirely assigned to one company, and the winning company was responsible for development of the projects through execution and delivery of the work. Requirements to meet the AQUA criteria were not included in the bidding process, and therefore the questionnaire was applied by considering the project as completed, i.e., the reality found in the building as it is today.

The building studied was located in the midst of existing buildings of the Engineering School, on the fourth university campus plateau. It includes classrooms and support areas such as rest rooms, storage rooms and technical rooms distributed on four stories, plus auditoriums located on the first floor only. The building was built in the traditional construction system, with reinforced concrete, masonry walls, on-site precast ceilings, asbestos roof, and large spanning windows. A location plan of the building on campus and a schematic floor plan of the building can be seen in Figures 1 and 2.

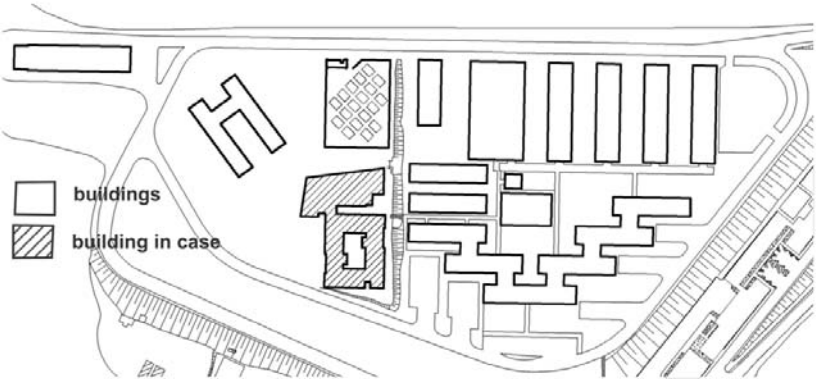

Figure 1. Location plan of the building.

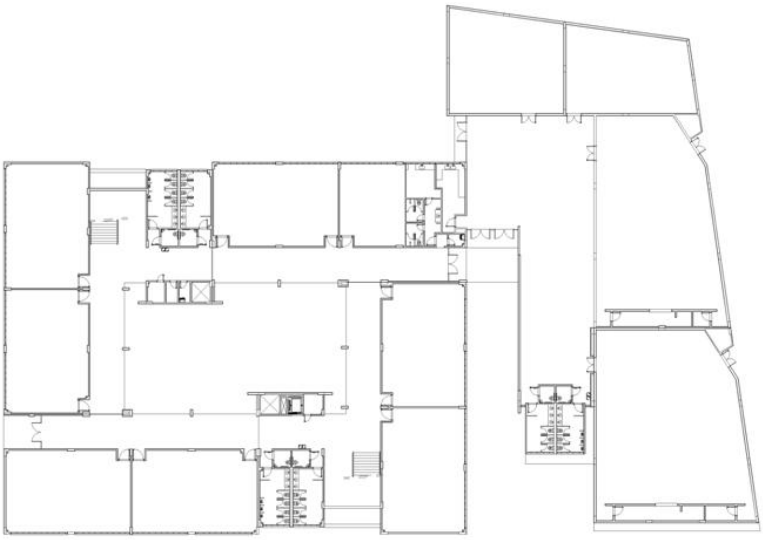
Figure 2. Floor plan of the building.

4.1 *Category 1 - Relationship between the Building and its Surroundings*

Concerns 1.1.2 and 1.3.5 refer to managing the means of transportation and ensuring the neighborhood's right to peace, respectively, and because they are not directly related to the design stage of the building project they were not considered in this work. The remaining answers for Category 1 of the TR are shown in Table 1.

Table 1 shows that environmental requirements are still only incidentally considered in the project since only 10 "Yes" responses were given. On the other hand, the "Partially" responses, which represent the majority together with the negative answers, are opportunities for recommendations to be followed in the development of new projects focusing on better performance for new educational buildings.

For category 1, negative responses refer to the discontinuity of solutions for the preservation of the local biodiversity and ecosystem (the implementation of the building did not consider an increased vegetation area; also, plant species adapted to the climate and terrain were not chosen), and to the fact that disturbances caused by noisy activities were not considered. "Partial" responses refer to the adoption of measures for rational exploitation of locally available networks and resources, the implementation of green areas in the terrain (there was a decrease in the existing green area since it was transferred to a distant location), and measures taken to limit the disturbances caused by wind, rainfall, sun exposure and external noise. "Not applicable" responses refer to the fact that flood risk was not considered since the building is located at a high altitude.

Table 1. Category 1 – Results

Subcategory/Concern	Yes	No	Partially	Not applicable	Overall
1.1			1		1
1.1.1	1		1		2
1.1.3		3	1		4
1.1.4				6	6
1.2			1		1
1.2.1			5		5
1.2.2		1	3		4
1.2.3	3				3
1.2.4	1		1		2
1.3			1		1
1.3.1	1				1
1.3.2	1				1
1.3.3	2				2
1.3.4	1				1
Overall	10	04	14	06	34

4.2 *Category 7 - Maintenance - Continuity of Environmental Performance*

Concerns 7.1.1, 7.2.1, 7.3.1 and 7.4.1 refer to the availability of resources needed to monitor and control performance during use and operation of the building. Because they do not concern the design stage of the building project they were not considered in this work.
Results for this category are shown in Table 2.

Table 2. Assessment Results for Category 7

Subcategory/Concern	Yes	No	Partially	Not applicable	Overall
7.1.2	2		1	1	4
7.1.3	3		1		4
7.2.2	2		1		3
7.2.3	1		1		2
7.3.2	1				1
7.3.3	2			1	3
7.4.2	3				3
7.4.3		1		2	3
Overall	14	1	4	4	23

Table 2 shows that the number of positive measures taken for easy maintenance outweigh the 'negative' and 'partially' results. The consideration of maintenance during the design phase has been defended in the literature (Antunes & Calmon (2005), Loosemore & Chandra, 2012 and Sanches & Fabrício, 2009). The inclusion of maintenance in the initial stages of a project allows for a better match of activities to be carried out over the life of a building, ensuring its better functioning and use.

In this category, the negative response refers to the confinement of pipes, which hinders or impairs maintenance activities. Partial responses are due to maintenance activities without disturbing occupants, access to cooling and ventilation systems, and sector-oriented pipe design. Because it is a small building with simple construction elements, the 'not applicable' responses refer to a lack of building automation systems and cable systems for access to lighting fixtures installed at isolated points, as well as access to thermal insulation elements and water treatment points, since these do not occur in this building.

4.3 *Recommendations*

Regarding the architectural design, based on the 'negative' and 'partially' responses found in the requirement analysis for TR Categories 1 and 7, we recommend that the following measures be taken in new projects to achieve better performance for new buildings to be constructed on the UFJF campus:

- inclusion of environmental performance requirements in the bidding process. In Brazil, the new performance standard (ABNT, 2013) includes a number of requirements to be met for residential buildings, including smaller ones (up to five floors);
- an attempt to preserve the local biodiversity and ecosystem, or increase green areas and choice of vegetation adapted to the climate and terrain;
- survey and consideration of weather conditions to deal with the disturbances caused by winds, rainfall, sun exposure and external noise, in the quest for quality outdoor spaces for users. According to the TR (Fundação Vanzolin, 2007), landscape design is a means to address these various concerns, such as protection against the sun and wind. However, they can be sources of noise or allergies. Furthermore, passive elements of design should be studied such as "*brise-soleils*" (sun-shading), acoustic barriers, double walls, among others;
- address accessibility to different elements of the systems and avoid confinement of pipes, in order to facilitate completion of maintenance activities.

5 FINAL CONSIDERATIONS

This paper introduced AQUA, the Brazilian system for environmental certification, and analyzed Categories 1 and 7 from among fourteen categories, since these are more closely related to the shape of a building. Subsequently, we conducted a case study for an educational building recently built in a federal public institution, so that we could check its performance against the requirements relative to the form of the project. This building was built by the conventional method (reinforced concrete and masonry walls) following the bidding process required for public works in Brazil, which did not include environmental certification requirements.

Results indicate that some measures for implementation of the project and neighborhood impacts could be better considered. On the other hand, most of the maintenance measures have already been met. From this result recommendations were proposed for new projects in order to improve their performance.

It should be noted that in the case of public works, demands for better environmental performance should already be included in the bidding process, so that they could be considered in new projects and works.

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The implicit definition of 'utility' in the sustainable building assessment methods.

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ABSTRACT: The research is focused on the concept of 'utility' regarding the sustainable building assessment methods. The study presented is part of a wider research that analyses the sustainable building assessment methods regarding the challenge of sustainability. Keeping in mind that the condition of sustainability is the material cycles closure, we highlight the place that 'utility' occupies in the measure of the sustainability. We explore how the standards of LCA and sustainable building assessment deal with this question. Then we point out the impossibility of an objective measurement of utility and the fact that the methodologies adopt a conventional definition of this concept. Finally we contribute a formulation that has to allow us, in future works, analysing the definition of utility adopted by the different methodologies and the corresponding implicit judgment values.

1 THE SUSTAINABILITY AND THE LIMITATION OF THE AVAILABLE MATERIAL FLOWS

1.1 *Sustainability: our point of view*

The spreading of the use of the word sustainable in all the fields, from scientific literature to the daily speech, as well as its different interpretations, nearly require, in a research as this one, pay a minimum attention to establish the point of view adopted to avoid mistakes. Such as J. M Naredo (Naredo & Valero Capilla 1999) has explained, the word 'sustainable' appeared related with the environmental worries as an adjective of the idea of the 'sustainable development'. In fact 'sustainable' was not a strange word for economists devoted to development, because they have used this adjective to talk about the 'self-sustained growth'. For this reason it was easily acceptable. But this notion have a high degree of uncertainty because it links in a single expresión the worry about the economic development, normally defined in the economics file as growth of the production in monetary terms, with the intention to maintain the health of the ecosystems, without specifying how these would be compatible, which has caused a rhetorical use. In fact, the definition in the Brundtland report (Comissió Mundial sobre el Medi Ambient 1987, p. 41), became canonical, keeps this ambiguity. However, the original worry for the physical viability of the human systems has brought some authors to go more deeply into the research of the content of the sustainability notion.

«The greater part of the current lack of definition comes from the insistence of reconciling the economic growth (or development) with the idea of sustainability, when each of these aspects are referred to different levels of abstraction and reasoning systems». The notions of economic growth –and development– are based on the usual idea of economic system and work with the corresponding units of the homogeneous monetary aggregates of 'production' and their derivated units. However, the worry for the sustainability is based on the singular and heterogeneous physical processes (Naredo & Valero Capilla 1999, p. 60).

All the organisms, populations and ecosystems of the earth are alive thanks to the continuous degradation of the matter and energy involved in the material cycles. But as the earth has finite material resources, the maintenance of the life is only viable thanks to the fact that the biosphere is an open system which receives a continuous energetic flow from the sun which allows counteracting the degradation. Whereas the idea of the economic system is understood as a closed system and suppose that the flow of the investment can counteract the deterioration caused on its obtaining, following the model of a continuous movement machine. The conclusions are that as the opening of the system and the degradation of the matter, very important questions in the description of the biosphere, do not have reflection in the idea of the economic system, it is not possible, from this point of view, deal with the sustainability in a coherent way. And, on the other hand, that the sustainability can be defined as the condition of the closure of material cycles, which has as a corollary the need of basing all the processes on the solar energy flow. This last point of view, designed as a strong sustainability, is the one used here (Naredo & Valero Capilla 1999, p. 64).

Some authors have thought that the economic growth and the sustainability can be compatible through the idea of the decoupling. This idea supposes that even though the monetary aggregates which represent the production of the wealth carry on growing, the material support of this production can be reduced thanks to technological changes. Other authors, however, have demonstrated in an empirical way and with recent data the falseness of this hypothesis, showing that the absolute decoupling –the absolute reduction of troughput material at a global level– is just «a myth» (Jackson 2009, p. 67-86, cap. 5).

1.2 *Material cycles and flows*

Material cycles have been on earth since its origin and shaped life, while life deeply changed these cycles. This coevolution is the one that has determined the conditions of the environment which we all depend on. The deep and fast modification of the material cycles established like this supposes, from the point of view of the life and specifically the human life, the degradation of the environment. In fact, as R. Margalef points out (Margalef 1982, p. 325;Margalef 1992, p. 88) any pollution problem can be described as an illness of the transport of the ecosystems and the first step for the solution is recognize the disturbed cycle.

From a global perspective, the movement of materials in the biosphere appears as a cycle, in other words, it is like a journey of some materials tracing wide or short ways through the hydrosphere, the lithosphere, the atmosphere, or through their limits, and in a determined speed. From the point of view of a particular system, however, it is more useful to pay attention how this movement of materials crosses the borders of the delimited system and then represent it as a flow. Thus, when the sustainability of a system is considered, we can simply take into account if the inflows and outflows are compatible with the corresponding natural cycles. In this way we are taking into account the compatibility with the rest of the ecosystem.

All the living being are situated in any point of the material cycles in order to obtain a flow of utile resources for its life, either to use on its living structure or on external structures, which allow a higher control of the material cycles. If the human being is different from the rest of the living beings is because of the big proportion of the resources which uses for the external structures in comparison with its living structure (Margalef 1982, p. 307;Margalef 1991, p. 250). The increase of these structures has supposed an immoderate interference in the material cycles and the fast transformation of the environment, putting in danger the bases of its own existence. The evidences of different processes of environmental damages, exposed by the scientific community, are not more than concretions of the perturbation of each of the material cycles. It explains, therefore, the need of the establishment of limits of the flows involved in all the human processes, in each of the relevant areas from the point of view of each material cycle. Without going into detail about the discussion of the establishment of these particular limits, it is necessary to signal that it is from the best scientific knowledge of the moment that it is necessary to establish them. In the same way, as it has been done in concrete cases, it is necessary to consider the evolution of the limitations of the flows in the time, establishing target reduction scenarios (Zimmermann *et al.* 2005). In conclusion, the condition of sustainability supposes the control of the material flows of the human technical processes.

2 THE SUSTAINABILITY IN THE PARTICULAR PROCESSES

2.1 *Consequences of the sustainability for the particular processes*

It has been usual to talk about the sustainability as an attribute of an object, whether it is a sheet of paper, a building or a city. The indiscriminate use of the adjective 'sustainable', mentioned above (sect. 1.1), supposes that the word is used to highlight a pretended or real paid attention in environmental questions, in a particular process, in comparison to the usual practise. But this use is too generic and a little bit useful to deal with the environmental problems. In order to establish a more restrictive and operative use of the word 'sustainable' applied to any particular process –the particular sustainability– is necessary to establish the relation with the definition of general sustainability. General sustainability can be defined as the limitation of the total flows of a substance in the relevant area; and the 'relevant area' as the biospheric area involved in the material cycle in question, for example the local, regional, global field or the hydrographic basin,.... Thus, for example, the relevant area for the liquid polluting substances can be water down of a hydrographic basin and for GEH substances the global field. The definition of particular sustainability has to be coherent with the condition of general sustainability.

The condition of general sustainability, as we have said, is the closure of the material cycles, which can be expressed for each resource and emission as a total limit flow.

$$F \leq F_{lim} \quad (1)$$

Where F = total flow; and F_{lim} = total limit flow.

The total flow is the sum of the corresponding flows to the particular processes in the relevant area.

$$F = f_1 + f_2 + \cdots + f_n = \sum_{i=1}^{n} f_i \quad (2)$$

Where fi = particular flow *i*th.

The other side of a particular process, and that justifies it, is the satisfaction of needs through the utility. And utility is always provided by a physical support that we can call satisfier (Max-Neef *et al.* 1994) and that constitutes the material flows so-called from the point of view of economics as goods, either economic or free. For the moment we will not talk about the question of the definition of necessity and utility, just say that the utility cancels the need, and with the ordinary idea it will be enough. What interests us, in the first place, is that a particular process generates a satisfier able to contribute utility, so the utility is a dependent magnitude of the satisfier: $u(s)$. In this expression s has to be understood as a qualitative variable: a unit of a concrete type of satisfier and u as a utility that we will suppose that is a measurable magnitude. On the other hand, a particular process generates a flow of the studied matter in such a way that an intensity of flow in respect of the utility can be defined, and it can be called ecological cost – inverse magnitude of the ecological efficiency.

$$c_i = \frac{f}{u(s_i)} \; ; \quad f = c_i \; u(s_i) \quad (3)$$

Where c_i = ecological cost; and $u(s_i)$ = utility of a unit of the satisfier *i*th.

Substituting the expression of the particular flow (3) in the expression of the total flow (2) we have:

$$F = c_1 u(s_1) + c_2 u(s_2) + \cdots + c_n u(s_n) = \sum_{i=1}^{n} c_i \, u(s_i) \quad (4)$$

that indicates that the total flow of a material, produced with the objective of contributing utility, depends on the chosen satisfier and on the ecological cost tied to this satisfier. If now we substitute (4) to the condition of general sustainability (1), we obtain

$$\sum_{i=1}^{n} c_i \, u(s_i) \leq F_{lím} \quad (5)$$

that shows that the condition of general sustainability limits the quantity of utility and/or the type (i) and quantity (n) of the satisfiers.

The limitation of resources is imperative since the point of view of the sustainability (Jackson 2009), above and beyond the difficulties that we might have to determine it exactly, and therefore the right-hand member can be considered theoretically fixed. Therefore, if we want to deal with the question of the satisfaction of the human need, we have to pay attention to the factors of the left-hand member. A usual way and very necessary to address the subject is to modify the satisfiers in such a manner that a satisfier provides the same utility with less ecological cost: it is the way of the efficiency through the technological evolution. Another way to address the efficiency is to pay attention to the relation between the satisfiers and the contribution of utilities, ensuring that we make the most of all the potential contribution of utilities of a satisfier: it is the way of the efficiency in the use of the resources –that is the grandmother's wisdom: 'turn off the light when you go out of the room'. This last treatment is related to the technology but overlaps the questions of behaviour and cultural factors. There is also the possibility to limit the consumption (*n*). But above and beyond the dimension of the satisfier, as showed in the left-hand member, there is the dimension of the utility –and its opposite: the need– and we have to remember that it has been left without defining and often remain defined implicitly and that is the factor that we deal with in this research.

2.2 *Indicators*

The structure of the methods of assessment and rating of the building is composed by a group of indicators. It is important to deal with this concept of indicator and some aspects of the classification of these. The review of the literature gives us some definitions of 'indicator' (Bossel *et al.* 1999;Castro Bonaño & Salvo Tierra 2001;OECD.Group on Environmental Performance 1993) mentioned in (Monterotti 2013, p. 73) (Agència Europea del Medi Ambient 1998;Malmqvist & Glaumann 2006). All the definitions incorporate the following aspects: it is a value that describes a more complex reality than its same magnitude and therefore synthesize the information. To highlight some aspects of the content of the term 'indicator', we are interested in telling the following definition, which is both descriptive, in the sense that takes into account the characteristics of what usually is understood as indicator, and normative, in the sense that the use that we do of the concept will be adjusted to this definition. An indicator is a –quantitative or qualitative– variable that is used for having a sufficient degree of correlation with one or different variables that determine the state of a system, which is the object of our interest. The fact that an indicator or a group are used instead of the group of variables that define the system is related to fundamental questions, as epistemological questions connected with the reality that we study, or with practical questions, as availability of data. In any event, a variable is never itself an indicator but it is used as an indicator when it is considered useful to do so.

The indicators that are part of the methods of sustainable building rating systems that interest us refer to the input and output flows of the system that is a building, with the limits that the methodology has marked for this system. If one describes the different causal steps that go since a particular process to the effects on the environment, a cause-effect chain can be described (Eriksson *et al.* 2005). The indicators, then, can be classified, as the place that occupy in this chain, with different names as state indicators, pressure indicators, response indicators,... (Bell & Morse 2012, p. 28) One can also form models of indicators choosing different points of the chain and defining in each an indicator. It is the case of the DPSIR model, Driving force (D), emissions to Pressure (P), midpoint changes to State (S) and end-point problems to Impact (I) of the European Agency of the Environment (Malmqvist & Glaumann 2006, p. 324). In any case, what interests us is that the indicator defined always has a causal connection, more or less close, to a flow generated by the process.

The other characteristic of the indicators used by the sustainable building rating systems is that always have to refer to what justifies the generation of a flow, in other words, the utility. This reference to the purpose is what makes possible the comparison between different cases and can let establish a measure of the sustainability. This question refers both to the field of the building sustainability assessment and to the most general field of the LCA methodology. In these two fields an effort of systematisation has been recently done through the formulation of standards, and therefore we are interested in studying how they deal with the question.

2.3 *The 'functional unit' and the 'functional equivalent'*

The UNE-EN ISO 1040:2006 and UNE-EN 1044:2006 standardise the LCA methodology. As it is established there, when a LCA of a product or service –i.e. of any process– is carried out it is done relatively to a unit of product designated as a 'functional unit'. «A functional unit is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results» (AENOR 2006a, p. 20). What is identified as a functional unit, therefore, is not necessarily a quantity of individual product but the quantity of a function identified that provides. It is necessary to highlight that this 'function' points out to the variable utility that we have defined above (sect. 2.1)

The standardisation of the building sustainability assessment is carried out in the set of standards UNE-EN 15643:2012. In that case we see that, in spite of the building sustainability evaluation supposes an analogous process to the LCA, here the concept of functional unit is not used but the 'functional equivalent', which is defined like this: «Quantified functional requirements and/or technical requirements for a building or an assembled system (part of works) for use as a basis for comparison» (AENOR 2011, p. 12). The concepts of functional unit and functional equivalent occupy the same place in each of the corresponding contexts. The relevant difference is that while in the first case a basic quantity of function or utility is isolated, in the second case a complete description of the types and level of corresponding utility to the process studied is done. We have to suppose that the different approach that the authors of the two standards assume, in each of the contexts, answers to supported reasons. We have to suppose that the difference is justified by the complexity of the utility that provides a building: the habitability.

In the LCA in general, when the comparison between two alternatives of product is treated, what is known as a 'comparative assertion', there is just the problem that one must to refer to the same functional unit of reference. In the same way, in the case of the assessment of the building, we will not find any problem in comparing two alternative projects of the same building that fulfil with the established functional equivalent. The problem of the reference to the utility appears when one wants to develop a measure of the sustainability of the building for any building. And it is necessary to remember at this point that the possibility to develop a measure of the sustainability of particular processes depends on the capacity of being applied in a general way (see equations (1) and (2)). In this case, the functional equivalent rarely coincides and therefore it is unavoidable a reference to the utility that allows not only the comparison between buildings –relative measure– but also the reference to the total flows that appears in the condition of sustainability.

When a methodology is formulated for a sustainable building rating system, it is obligated to define this reference to the utility. In fact, the indicators used in these methodologies, as we say in the section 2.2, always are a particular type: a quotient between an indicator and the unit of the defined habitability –operation that usually receives the name of 'normalisation' (Cole 1999, p. 8). The question that we set out in this research is to systematise the analysis of the definition of the unit of habitability used to let us analyse, in the future, the implicit judgment values in the chosen definition.

2.4 *The definition of 'need' and 'utility'*

In the section 2.1 we have not deeply talked about the symmetrical concepts of necessity and utility and we just said that the needs were cancelled by the utilities provided by the satisfiers. The development of the ideas has placed 'utility', and the possibility to measure it, as a central concept of the research, and therefore it is necessary to analyse it with more attention. In order to consider the question, we can go to the field of economics that has dealt deeply with it. The birth of economics was based in the study of the creation of wealth. Wealth was defined as all those objects that «are necessary, useful and pleasant to the human being» (Naredo 1987, p. 117). This link between wealth –as a production– and utility, what satisfies people, is the moral justification of the efforts for the increase of the production as well as for the study of the conditions that make this increase possible. This fact is what brought to the study of the utility and the reason why big efforts were done in order to define it as a measurable magnitude. However, as

J. M. Naredo shows, the idea of the measurability of the utility, either in cardinal or ordinal terms, was an illusion (Naredo 1987, esp. cap. 20).

In fact the impossibility of a strict definition and the quantification of the utility depend on the lack of definition of the concept of necessity. «As other concepts and words coming from the evolution of the human thought, the notion of necessity has become part of the common language, and even to the social sciences language, without defining its sctrict meaning: their limits are not exactly pointed out neither what is considered to extend or cut off them». This impossibility is determined by the fact that the needs are based on the human appetite and these depend on their social and ideological context. This is why it is not «possible to specify these limits through a fractional analytic effort which finally results in the formulation of a really objective theory of human needs» (Naredo 1987, p. 53-54).

Keeping references contributed in mind to justify the impossibility to work with a definition and an objective quantification of the utility. On the other band, the application of the condition of sustainability to the particular processes has brought us to establish the need to measure the utility, as the magnitude that justifies the allocation of resources. And in the concrete field of the sustainable building rating systems we have also seen the need to establish a unit of reference that defines and quantifies the habitability. The solution depend on understand that if we want to establish a measure of the sustainability of particular processes, we have to do a conventional definition and recognise that this definition will be based on a subjective value judgment. And we have to realise that all the sustainable building rating systems give a definition of this type and therefore they are based on a value judgment.

3 FORMULATION OF THE HABITABILITY FOR AN ANALYSIS

Having settled down the question of the utility of reference, we set out the notation and the methodology that will be useful –in future works– to analyse the definitions used by different methods or the definitions that are possible to use. This analysis will let us show the judgment values that are behind the use of the different definitions of utility used.

We have already commented that a need can be satisfied with different satisfiers and we have put aside the election of satisfier to focus on the question of utility. Suppose a need, a satisfier already selected, the particular process to obtain the satisfier and one of the flows that generates this process. We can conceive the satisfier in two parts. The first one is the detailed definition of all the physical conditions that the satisfier provides and we can express as a physical model (function σ). In the equation (3) we expressed the ecological cost as the quotient between the flow and the quantity of utility. But as we have seen in section 2.4 it does not have any sense to take the utility as an objectively measurable magnitude. Being realistic, we can substitute the expression of the ecological cost for a new one that has as a denominator the conditions of the satisfier, i.e. (σ), and we obtain:

$$c_s = \frac{f}{\sigma} \tag{6}$$

Where c_s = ecological cost of the satisfier; f = material flow; and σ = conditions of the satisfier.

The second part that defines the satisfier, therefore, is the defined environmental cost (c_s). So we have that the flow can be expressed as the product of the two expressions that define the satisfier: the cost and the conditions. And at the same time we can develop the σ function, usually as a product of different factors:

$$f = c_s \ \sigma = c_s \, \alpha_1 \, \alpha_2 \, \dots \, \alpha_{n1} \tag{7}$$

The (f) flow is an indicator that does not comply with the condition that we established for an indicator of a sustainable building rating system, which is being relative to a unit of reference of the utility (sect. 2.2). This condition is the one that would allow the comparison between different buildings (sect. 2.3). It is whereas a total flow of the analysed process, relative to the ‘functional equivalent’. Define a conventional utility of reference means that some factors of the conditions of the satisfier (α_i) have to be designed as legitimate representatives of the concept of utility.

$$ind. = \frac{f}{\alpha_j\, \alpha_k \dots \alpha_m} = c_s\, \alpha_p\, \alpha_{\,q} \dots \alpha_{n-m} \qquad (8)$$

So the indicator of sustainability is defined as the quotient between the flow and these factors, which can be called 'defined utility' (u^*). On the other hand, the methodology of qualification, because of the condition of sustainability, will have to establish a restriction of this indicator, as a limit of the flow. In spite of not being the object of this research, we point out that some authors have worked in order to formulate methodologies to relate general limits and particular limits of resources (Zimmermann *et al.* 2005).

$$ind. = \frac{f}{u^*} = c_s\, \alpha_p\, \alpha_{\,q} \dots \alpha_{n-m} \;\leq f_{lím} \qquad (9)$$

Where u^* = defined utility; and f_{lim} = assigned flow limit.

Having this last expression obtained, we can describe the meaning of each part. The indicator will be subjected to a restriction ($\leq f_{lim}$). The defined utility (u^*) can be understood as what justifies the allocation of resources, in the sense that an increase of (u^*) allows an increase of (f) without the indicator varies, and therefore receiving the same rate. On the other hand, all the factors of the right-hand member, either the environmental cost of the satisfier and the rest of the factors of the conditions of the satisfier that have not been considered as a legitimate utility, became subjected to the restriction and its increase supposes the proportional increase of the indicator, giving a more unfavourable rate.

To deal with the analysis of the definition of utility used for a method, therefore, the development and the notation contributed can be used, isolating the defined utility and studying the factors included in this definition and then, we can study the implicit judgment values in the used definition of utility.

4 CONCLUSIONS

The condition of sustainability supposes the limitation of the available resources and, on the other hand, it involves the concept of utility that can be understood as the purpose that legitimates the allocation of resources. In spite of the centrality of the concept of utility for the sustainability, it is not possible to make an objective and measurable definition. That is why the sustainable building rating methods are doomed to use any conventional definition of 'utility' of the buildings or 'habitability' –often in an implicit way. With the aim of analyse the definitions of utility that the methodologies use we have developed, in this study, a theoretical framework and a formulation showing the factors that are considered as legitimate representatives of the utility, and the other ones that are submitted to restriction. The fact that the methods do not explain this definition is a factor of lack of transparency for the comparison of their results.

The theoretical framework and the formulation contributed let us, from now, analyse rigorously the definition of habitability used by the methodologies. It also let us uses the comparative analysis and reflect on possible alternative definitions. At the same time, this analysis will be useful to show the implicit judgment values in the definitions of utility used.

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A Review of Research Investigating Indoor Environmental Quality in Green Buildings

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ABSTRACT: Although it has been claimed that green buildings offer improved indoor environmental quality (IEQ) over conventional buildings, there is little empirical evidence in the literature to substantiate these claims. This research aimed to review the literature on IEQ in green buildings. The literature was analyzed based on parameters such as the literature's country of origin, year of publication, type and sample of buildings studied and specific IEQ aspects studied. The review showed the need for research that analyzed larger green building samples, that relied on on-site physical measurements and that focused on buildings other than office buildings. Papers reviewed showed consensus among researchers on how green buildings improved air quality, and worsened acoustics, but less consensus on how thermal comfort and lighting performed. Green building occupants were also found in general to be more satisfied with thermal comfort and air quality but less satisfied with acoustics than occupants in conventional buildings.

1 INTRODUCTION

Although there are claims to the improved indoor environmental quality (IEQ) of green buildings, there is little empirical evidence in the field to substantiate these claims. This is because most research and industry practices seem to have focused on energy as the main driver to building green; and thus on improving the energy-effectiveness of green buildings with little consideration to other aspects such as IEQ.

This research is based on the premise that assessing and improving IEQ in green buildings is a necessity given the growth of the green building market. Since the foundation of the Canada Green Building Council (CaGBC) in 2002 more than 4400 buildings have registered for Leadership in Energy and Environmental Design (LEED) certification, with more than 1200 projects already certified (CaGBC,2013). This focus on IEQ is also needed to address the weaknesses of the literature on the topic. Only small-scale post occupancy surveys about IEQ appear to have been conducted up to this point, raising concerns about the accuracy of their results and the ability to extend them to other green buildings (Birt and Newsham 2009). These results have also sometimes been contradictory, reinforcing the need for more research in the field (Issa et al., 2011).

The goal of this research is to conduct a thorough review of the literature on IEQ in green buildings to establish benchmarks about their performance and pave the way for further research in the field. The review will investigate the location and timing of relevant research studies and analyze methods used to conduct them as well as the results put forward by them. It should provide researchers and practitioners interested in the post-occupancy evaluation of green buildings with a better understanding of knowledge gaps in the field as well as the literature's strengths and limitations.

2 RESEARCH METHODS

The research involved identifying the literature focusing on IEQ in green buildings; three databases were investigated: Scopus, Science Direct, and Compendex Web; using the keywords “Indoor Environmental Quality”, “Green Buildings”, and “Occupant Satisfaction”. Given the resulting large number of journal and conference papers, the search was limited by combining keywords together (e.g. “Indoor Environmental Quality” & “Green Buildings”), and skimming through the papers’ abstracts to determine their relevancy. Papers were included in the analysis if they focused on investigating one or more IEQ aspects. They were discarded if they did not focus on green buildings specifically. This resulted in a total of 18 papers that focused on both IEQ and green buildings.

The research involved developing a database to analyze these papers based on the parameters in Table 1. In addition to these parameters, Table 1 also includes the section or subsection within the paper where every parameter is addressed, and the figure(s) if applicable depicting the analysis of every parameter.

Table 1. The parameters of analysis.

Parameters	Section	Figures
Country of origin and year of publication	3.1	1 and 2
Building types	3.2.1	3
Number of green versus non-green buildings	3.2.2	4
Rating systems	3.2.3	5
Methods and data	3.3.1	6
Specific IEQ aspects	3.3.2	7
Results	3.4	8

3 ANALYSIS RESULTS AND DISCUSSION

This section presents the literature review results as per the parameters in Table 1.

3.1 *Country of origin and year of publication*

The review involved analyzing research studies based on their country of origin. As shown in Figure 1, two countries seem to lead research in the field. More than 40% of studies on the topic were carried out in The U.S. (e.g. Abbaszadeh et al., 2006 and Kelting & Montoya, 2011), Australia came in second, with approximately 27% of all papers identified (e.g. Gou et al., 2013and Paul & Taylor, 2008). Only two studies were conducted in Canada (Issa et al., 2011 and Newsham et al., 2012), highlighting the need for more research on Canadian green buildings.

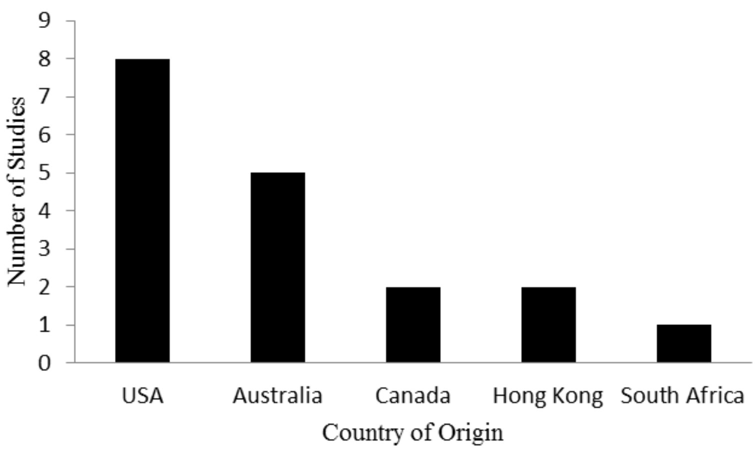

Figure 1. Distribution of research studies per country of origin.

The reviewed papers were also analyzed per year of publication. Figure 2 shows how the number of relevant papers increased significantly over the last three years, reflecting an increasing interest in green building research.

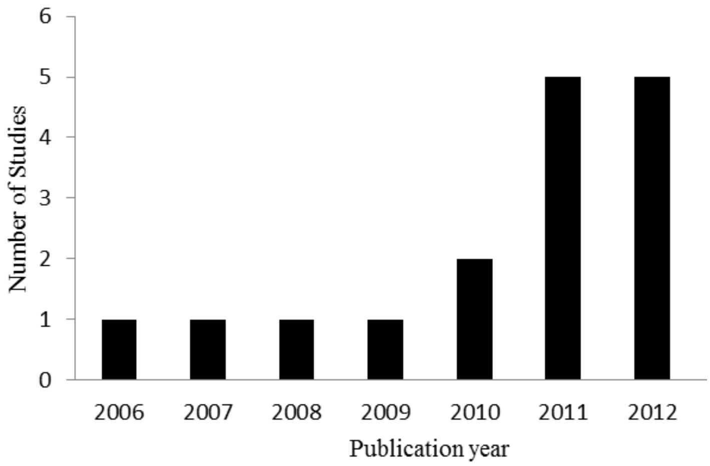

Figure 2. Distribution of research studies per year of publication.

3.2 *Buildings analyzed*

This subsection focuses on analyzing the specific types of buildings investigated in the studies reviewed, their level of greenness and the rating systems used to certify them.

3.2.1 *Building types*

As depicted in Figure 3, almost 50% of all buildings analyzed were office buildings (e.g. Singh et al., 2010 and Thatchera & Milner, 2012); a result hardly surprising given that office buildings tend to make up the majority of the building stock in the developed world, including Canada (CaGBC, 2013). This focus on office buildings could be due to the potential financial implications of doing. There are claims made by green building proponents that improving these buildings' IEQ would improve employees' health and productivity, and thus decrease related long-term business costs (Newsham et al. 2012) making their analysis of critical importance.

Twenty percent were institutional buildings (i.e. schools and universities) (e.g. Baker, 2011 and Issa et al., 2011), reflecting an interest in these buildings that could be due to the long-term goal of improving students and teachers' health, performance, and well-being (Issa et al. 2011).

About 17% of all studies investigated samples of different building types (e.g. Leaman et al., 2007 and Brager & Baker, 2009). Very few studies focused on residential buildings (e.g. houses and condominium buildings), the lack of focus on residential buildings could be due to the erroneous perception that those buildings do not have the same long-term financial implications as office buildings, highlighting the need for more research on residential buildings. This perception ignores the evidence in the literature linking improved IEQ in homes to improved occupants' health and the potential long-term health savings derived from doing so (Kovesi et al., 2007).

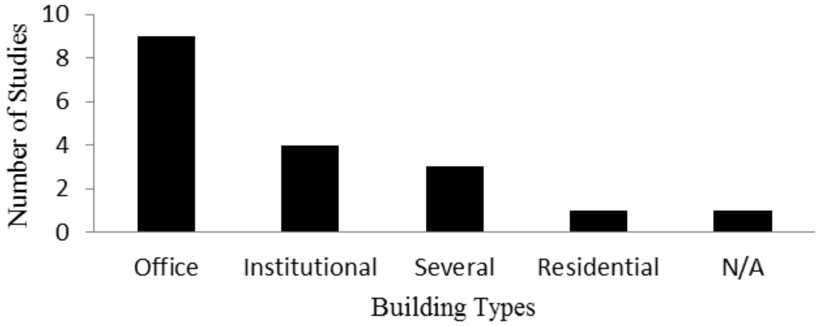

Figure 3. Distribution of research studies per building type.

3.2.2 *Number of green versus non-green buildings*

Fifty percent of all studies reviewed compared green buildings to non-green ones (e.g. Abbaszadeh et al., 2006 and Baker, 2011) with the other half focusing on assessing IEQ in green buildings solely (e.g. Singh et al., 2010 and Thatchera & Milner, 2012). A total of 140 buildings versus 650 non-green buildings were analyzed in all papers: an imbalance most probably due to the relative small ratio of green buildings to total existing buildings. Figure 4 shows how 60% of all studies used small sample sizes of less than 10 green buildings (e.g. Paul & Taylor, 2008 and Konis, 2013). This highlights an important limitation of existing research that makes it difficult to generalize existing results and reinforces the need for research evaluating larger building samples.

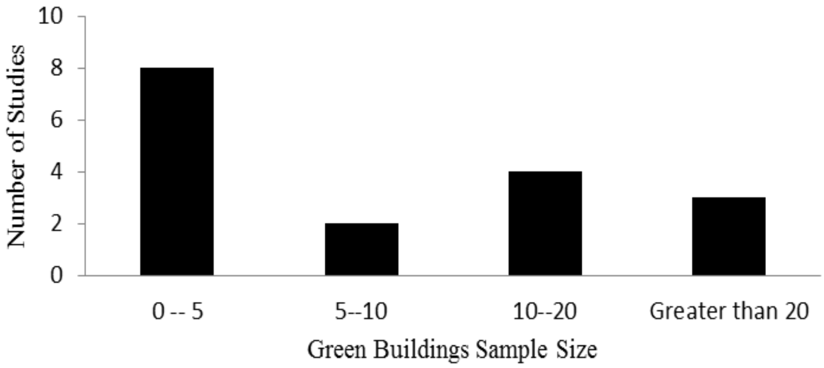

Figure 4. Distribution of research studies per number of green buildings.

3.2.3 *Rating systems*

Figure 5 shows how more than 50% of the studies reviewed focused on analyzing LEED buildings (e.g. Issa et al., 2011 and Singh et al., 2010). Seventy-five LEED buildings were analyzed in total in all studies; an indication of the popularity of the system in the green building market. The analysis also showed how green buildings certified using other rating systems received a lot less attention in the literature. Two studies focused on green buildings using the Green Building Label system (GBL) (e.g. Gou et al., 2013); another two on buildings using Green Star (Cladingboel et al., 2011 and Thatchera & Milner, 2012), and another two on buildings not accredited using any existing rating system (Abbaszadeh et al., 2006 and Baker, 2011).

Surprisingly, a number of studies did not specify the rating system used to certify buildings analyzed. Only one study (Gou et al. 2012a) analyzed green buildings certified using different rating systems at the same time. Despite the popularity of the Building Owners and Managers Association Building Environmental Standards (BOMA BESt) in North America, surprisingly, no research seems to have assessed these buildings' IEQ. These results highlight the need to consider buildings using other rating systems in order to enable IEQ cross-system comparisons.

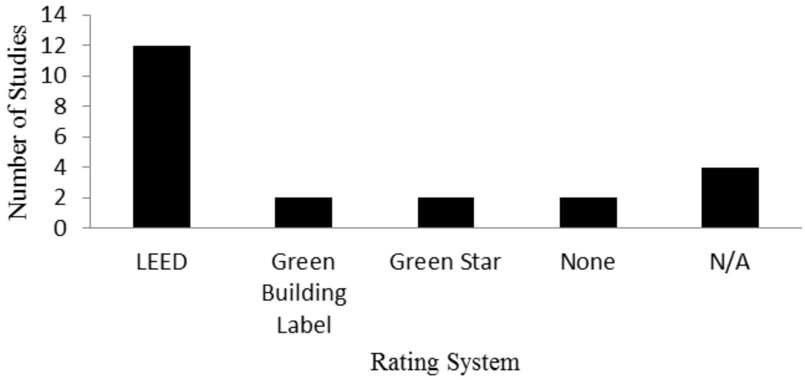

Figure 5. Distribution of research studies per rating system used.

3.3 *Research methods*

This subsection focuses on analyzing the specific research methods used to investigate green buildings' IEQ and the specific IEQ aspects analyzed in the studies reviewed.

3.3.1 *Methods and data*

As depicted in Figure 6, occupant surveys seemed to be the main method used to investigate IEQ in green buildings. Seventy percent of all studies used occupant surveys (e.g. Paul & Taylor, 2008 and Beauregard et al., 2011). Approximately, 40,000 occupants were surveyed in all of these studies, with one study alone (Abbaszadeh et al., 2006) surveying over 33,300 occupants.

Twenty six percent of the studies used the Building Use Studies (BUS) Occupant Survey Method; a benchmarking comprehensive method originally developed in the UK and used to assess users' needs in a range of building types (Gou et al., 2012b).

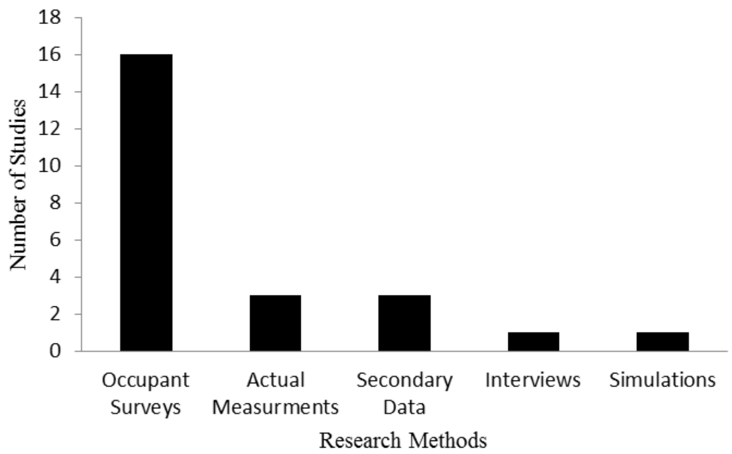

Figure 6. Distribution of research studies per methods and data.

Surprisingly, only three studies relied on actual physical measurements (Konis, 2013, Deuble & de Dear, 2012 and Newsham et al., 2012), highlighting the need for research that focuses on validating IEQ using on-site physical measurements due to their objective nature. The lack of actual physical measurements could be due to the fact that these require time, effort, and money; with the need for specialized equipment, personnel training, and field work; making them more difficult to conduct. The three studies that relied on them complemented and validated them with actual occupant surveys. Only one study (Cladingboel et al., 2011) relied on computer design simulations to test the thermal efficiency of their design.

Fourteen of the eighteen studies reviewed used statistics to analyse the results, highlighting an important strength of the existing literature.

3.3.2 *Specific IEQ aspects*

Four main IEQ aspects were assessed in the studies reviewed: Thermal comfort, Air quality, Lighting, and Acoustics. Figure 7 depicts the number of studies investigating each aspect.

More than 50% of the studies reviewed investigated the four aspects together (e.g. Issa et al., 2011 and Singh et al., 2010). Every other study assessed either one or two aspects at most (e.g. Cladingboel et al., 2011 and Lee, 2010). While there is value to investigating the four aspects together to get a comprehensive understanding of how they vary in relation to one another, focusing on every aspect separately allows for a more in-depth assessment of each. Thermal comfort appeared to be the IEQ aspect the most researched in the literature, most probably due to the tight relationship between thermal comfort; heating, ventilation, and air-conditioning; and energy consumption as the main driver to building green.

Lighting and Acoustics appeared to be the ones the least investigated at 65% and 60% respectively. This could be due to the fact that very few green building rating systems emphasize these aspects in general, thus the need for further research on them.

Given the tight link between IEQ and building occupancy, all studies extended to analyzing building occupancy through occupant surveys. The popularity of occupant surveys could be due to the relative ease of conducting them in comparison to other research methods. These surveys involved assessing aspects such as overall occupant satisfaction, productivity, performance, and health. Only 35% of the studies investigated all of those aspects together (e.g. Abbaszadeh et al., 2006 and Baker, 2011); the remaining focused only on occupant satisfaction with the overall indoor environment.

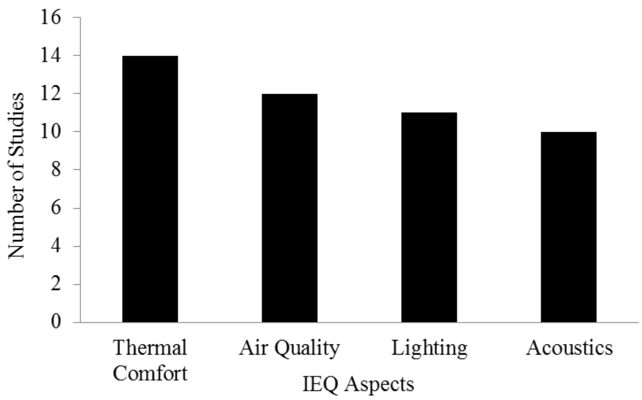

Figure 7. Distribution of research studies per IEQ aspects.

3.4 *Results*

This section presents a review of the studies' results to better understand how IEQ varies in green buildings and its effects on building occupants. Figure 8 summarizes these results.

Seven out of ten studies found air quality to have improved in green buildings (e.g. Gou et al., 2012b and Leaman et al, 2007). This was the aspect occupants were most satisfied with and the one that was found to have improved in most studies, showing a high level of agreement among researchers over its performance. Only five out of eleven studies showed an improvement in lighting (e.g. Konis, 2013 and Kelting & Montoya, 2011), demonstrating a lack of consensus over its performance and thus the need for more research on it. Only six studies out of twelve found that thermal comfort had improved in green buildings (e.g. Abbaszadeh et al., 2006 and Issa et al., 2011). The other six studies found thermal comfort in green buildings to either be on par with thermal comfort in conventional buildings or worse, suggesting the need for further research to reach more definitive conclusions. These results also reinforce the need to examine more closely the variations in performance across the different studies to better explain them. For the studies that used both physical measurements and occupant surveys, the results were surprisingly not always in line. Deuble & de Dear (2012) compared a mechanically ventilated green building to a naturally ventilated one and found that although the mechanically ventilated building performed better, occupants in the naturally ventilated one were more satisfied.

This shows the need to make the distinction between objective assessments of IEQ performance and subjective occupant perceptions of performance as those do not always match.

On the other hand, acoustics was found to be worse in six out of eight studies (e.g. Gou et al., 2013, Leaman et al, 2007). Lee Y. (2010) compared acoustics in five different office layouts in LEED buildings and found that high cubicle offices showed significantly lower levels of occupant satisfaction with acoustics, with low cubicle offices showing the lowest satisfaction levels of all. This dissatisfaction could be due to that fact that this aspect tends to be deemphasized, if not completely ignored in existing rating systems, reinforcing therefore the need for further research on it to improve its performance.

Given how the studies reviewed linked improved IEQ to improved satisfaction, comfort and performance, the research entailed reviewing results involving occupants. More than 90% of all occupants surveyed in these studies were satisfied with their green buildings' IEQ (e.g. Abbaszadeh et al., 2006 and Thatchera & Milner, 2012), showing high levels of consensus over occupants' perception of their indoor environment. Other studies noticed an improvement in occupants' well-being, productivity, and performance (e.g. Singh et al., 2010 and Issa et al., 2011). Despite some dissatisfaction from some occupants with some IEQ aspects (e.g. acoustics), occupants generally tended to forgive the inadequacies of their environments (Gou et al., 2013).

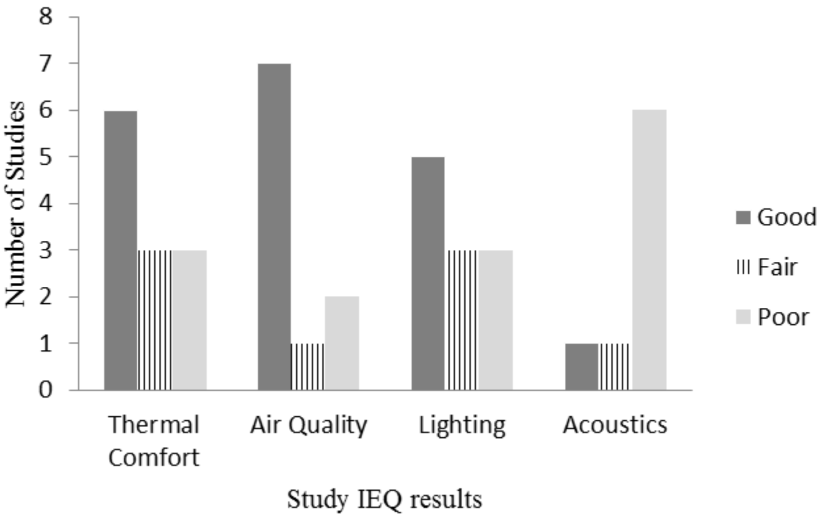

Figure 8. Distribution of research studies per IEQ results.

4 CONCLUSION

Despite the increasing interest in green buildings, there are only a few studies investigating their IEQ, and providing empirical evidence to their superiority over conventional buildings. This literature review showed how green building occupants tended to be on average more satisfied with thermal comfort and air quality than occupants in conventional buildings but largely dissatisfied with acoustics, highlighting the need for more research on acoustics.

This literature review also revealed the need to increase research in the field by analyzing larger samples of green buildings and using actual empirical data in the analysis. Larger-scale studies using on-site physical measurements are needed to reach consensus and allow researchers to draw broader conclusions about the green buildings' IEQ. There is also a need to focus on evaluating buildings other than office buildings to better understand how IEQ varies across different building types and industry sectors.

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Sustainable Construction Key Indicators

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ABSTRACT: Sustainable building is a concept that began its development nearly two decades ago. With sustainable buildings, it is intended to establish building practices that allow minimizing the buildings impacts, build and manage buildings with an adequate balance between environment, society and economy.
However, besides the importance of this concept, its broader implementation is not yet a reality. Several studies have been developed with the goal of understand the reason of these weak implementation. They have concluded that one of the main reasons is because the building stakeholders still consider sustainable practices more expensive, although several studies state the contrary. In order to potentiate the implementation of these practices, a work will be developed in order to perform a cost-benefit analysis of sustainable construction solutions.
In order to perform this work, it was necessary, in an initial stage, to define the key indicators that should be considered in order to assess the main aspects of sustainable construction. This paper intends to present the analysis that was performed in order to select these indicators.

1 INTRODUCTION

The buildings environmental impact has been a growing concern across the last decades. The relation between the planet environmental problems and the building sector is proven and accepted. Thus, there is an increasing demand for environmental friendly construction practices in order to minimize the building sector negative impacts (Cole 1999).

Due to these concerns, the necessity to develop a set of metrics in order to evaluate the buildings environmental impacts has emerged. Consequently, it was also necessary to establish benchmarks to these metrics. Thus, several entities have developed several sustainable building assessment methodologies. These methodologies have defined reference practices and have contributed to the implementation of sustainable development in the building sector (Ding 2008). These systems also allow to assess and monitor the buildings performance and to disseminate the importance of adopting sustainable practices.

In their beginning, these methodologies focused only on environmental indicators. However, with time, it was possible to understand the importance of the social and economic issues, regarding the buildings sustainability. Therefore, social and economic indicators began to be considered in these methodologies. Generally, building sustainability assessment (BSA) tools evaluate the buildings sustainability level through the aggregation of the building performance in a group of sustainability indicators.

The first developed BSA tool was BREEAM - *Building Research Establishment Environmental Assessment Methodology* (BREEAM 2012), in 1990. After this, other BSA tools were developed such as: LEED - *Leadership in energy and environmental design* (LEED 2013), developed in the United States of America, SBTool – Sustainable Building Tool (iiSBE 2012) developed by *International Initiative for a Sustainable Built Environment* (iiSBE), CASBEE - *Comprehen-*

sive Assessment System for Building Environmental Efficiency (CASBEE 2012) developed in Japan, among many other.

Each one of these tools defines their own set of sustainability indicators depending on the sociocultural environment since the importance of each indicator is different in different contexts. Therefore, several studies (Alwaer and Clements-Croome 2010, Bragança, Mateus et al. 2010, Chen, Okudan et al. 2010) were developed with the goal of develop a specific set of indicators applied to a specific location or type of building. However, these specificities make each tool very different from each other. These differences also led to a problem, since they make the comparison of results obtained through different methodologies difficult (Huovila, 2012).

In order to overcome these constraints, the two main standardization organizations, European Normalization Committee (CEN) and the International Standardization Organization (ISO) have been developed work with the goal of standardize the sustainable construction assessment (Mateus and Bragança 2011, Alyami and Rezgui 2012).

The goal of most BSA tools is mostly commercial. However, alongside with these tools, some initiatives have been developed by non-profit organizations (iiSBE, SB Challenge, SB Alliance), and through financed projects (LEnSE, SuPerBuildings, OPEN HOUSE), with the goal of defining and developing a set of sustainable buildings key indicators. These initiatives have taken into consideration the developments of several national and international BSA tools, the standards published by ISO and CEN as well as the opinion of some recognized European building construction stakeholders.

In order to study the sustainable construction it was very important to select the proper indicators. These indicators should include the main building impacts and assess the particular aspects of the socioeconomic context.

2 EUROPEAN PROJECTS

In order to define the sustainable building key indicators, four European initiatives have been analysed, the Sustainable Building Challenge 2011 and 2013 key indicators, the Sustainable Building Alliance, the SuPerBuildings and the OPEN HOUSE project. These initiatives are chosen because they are European initiatives that have performed recent work with the goal of define sustainable construction key indicators. In the next sections, a brief description of each of these initiatives is presented.

2.1 *SB Challenge - Sustainable Building Challenge*

The goal of the Sustainable Building Challenge (SB Challenge) process is to analyse and present innovative sustainable buildings techniques and concepts. It is organized by *International Initiative for a Sustainable Built Environment* (iiSBE) and has been an important part of *World Sustainable Building Conferences* the since 1998 (SBChallenge11 2011).

The participants of each SB Challenge edition identify buildings representative of their regions and assess their performance through a common BSA tool. In the first editions, the chosen tool was GBTool (the first version of SBTool). However, in the most recent editions, each participant is allowed to use any recognized assessment tool, as long as a set of key indicators is assessed.

Nevertheless, more focus has been given to the key indicators analysis, since it was very difficult to compare results obtained through different tools. Thus, one of the main aspects of this process is to define a set of metrics valid across different regions (SB Conferences 2013). The key indicators used in each edition were defined by iiSBE. This initiative was constituted by a broad range of members from different nationalities. These members are involved both in professional and academic building sector world. The multidisciplinarity of members ensures that the key indicators chosen were adequate to apply in different contexts.

2.2 *SB Alliance - Sustainable Building Alliance*

The Sustainable Building Alliance (SB Alliance) is a non-profit organization with the goal of createing an uniform language between the different BSA tools. In order to achieve this goal, SB alliance intends to define a set of sustainable building key indicators (Freyd 2012). This work has been performed by professional from several recognized institutions.

In order to select the indicators, this initiative have analysed several available BSA tools and their indicators as well as the released standards within the sustainability assessment theme. As expected, a very long list of indicators has been obtained in the analysis. The selection of the key indicators was performed through the analysis of each indicators and accordingly to the opinion of the SB Alliance members.

2.3 *SuPerBuildings - Sustainability and Performance assessment and benchmarking of Buildings*

The SuPerBuildings project (SuPerBuildings 2012) is an European project financed by the Seven Framework Programme (7FP). This project has selected and developed a set of key sustainability indicators for buildings. Besides, this project has also developed its own assessment methods and benchmarks. The project was developed considering new and existing buildings, different building types, different building stages and different national and local requirements. SuPerBuildings also intended to establish principles in order to help teams that want to develop new BSA tools (Huovila 2012).

The key indicators selection was performed taken into consideration the building life cycle. Both qualitative and quantitative indicators were chosen. However, regarding the qualitative ones, an additional effort was made in order to assure their reliability.

The key indicators selection was made with the consideration of the standards, initiatives and methodologies presented in Table 1.

Table 1. Initiatives, standards and BSA tools analysed by SuPerBuilings (Huovila 2012).

European And International Initiatives And Standardization Activities	National Sustainability Assessment Tools	
CEN TC 350	BREEAM & Code for Sustainable Homes (U. K.)	LEED (U.S.A.)
ISO TC59 SC17	DGNB (Germany)	SBtool CZ (Czech REpublic)
Sustainable Building Alliance (SBA)	PromisE (Finland)	Klima:aktiv Gebäude-standard (Austria)
UNEP SBCI	HQE (France)	TQB (Austria)
LEnSE	Valideo (Belgium)	GPR Gebouw (Netherlands)
Perfection	CASBEE (Japan)	

2.4 *OPEN HOUSE - Benchmarking and mainstreaming building sustainability in the UE based on transparency and openness from model to implementation*

The OPEN HOUSE project is also an European project financed by the Seven Framework Programme (7FP). The goal of this project was to develop and implement an European building sustainability assessment methodology. In order to achieve that goal, the project team encompasses different stakeholder across the Europe (OPEN HOUSE 2010).

The OPEN HOUSE methodology is based in the ISO and CEN standards and in the existent BSA tools, assessing the building life cycle.

The methodology was developed to be applied to office buildings and includes environment, social and economic indicators. Additionally OPEN HOUSE includes another three transversal aspects, namely, technical characteristics, process quality and location (Figure 1). However, the last category is extra since their evaluation object goes beyond the boundaries of the system (building and landscaping) and cannot be influenced by design options. (Zavrl, Tomsic et al. 2010).

OPEN HOUSE have 56 indicators distributed among these six categories. Some of these 56 indicators are pointed as key indicators and their assessment allow to obtain an initial idea about the building sustainability performance.

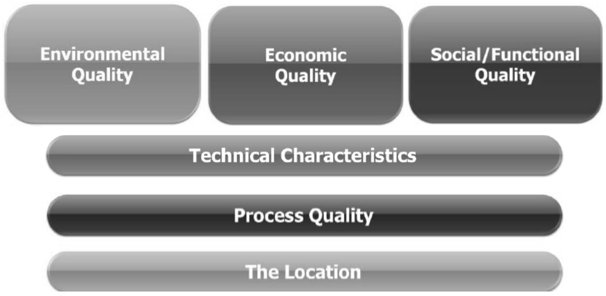

Figure 1. OPEN HOUSE categories (Zavrl, Tomsic et al. 2010).

3 EUROPEAN PROJECTS KEY INDICATORS

In order to select the key indicators that will be used in this study, the indicators selected by the four initiatives presented were analysed.

As exposed before, each one of the initiatives presented intended to select building sustainability key indicators. Therefore, the selection of a certain indicator by the majority of these initiates is a strong indication of its importance.

In Table 2 the indicators selected by the initiatives analysed were presented. Regarding the OPEN HOUSE methodology, only the main indicators were presented.

In this table, the indicators were grouped into sustainability categories. These categories were chosen accordingly to the findings of the initiatives.

Table 2 (part 1). Indicators selected by the different initiatives.

Indicators	SB Challenge11	SB Challenge14	SB Alliance	SuPerBuildings	OPEN HOUSE
Location					
Public transportation system	X	X			X
Proximity to amenities	X			X	
Site risk					X
Energy and emissions					
Building materials embodied energy	X				
Non-renewable primary energy	X	X	X	X	X
Renewable energy	X	X			X
Green House Gases Emissions	X	X	X	X	
Materials and waste					
Global warming potential					X
Ozone depletion potential					X
Acidification potential					X
Eutrophication potential					X
Photochemical oxidation potential					X
Reused materials	X				
Renewable materials	X				
Waste production			X	X (RCD)	X
Materials responsible source					X
Water					
Water consumption	X	X	X	X)	X
Potable water usage	X	X			
Water pollution (leaching)				X	
Land use and biodiversity					
Soil sealing				X	
Undisturbed areas contamination					X
Users health and comfort					
Lightning		X	X (i.d.)	X	X

Table 2 (part 2). Indicators selected by the different initiatives.

Thermal comfort		X	X	X	X
Indoor air quality	X	X	X	X	X
Acoustic comfort			X (i.d.)	X	X
Users comfort control					X
Electromagnetic pollution					X
Free barriers accessibility					X
Cyclists comfort					X
Society / culture					
Public accessibility					X
Esthetical quality				X	
Historical heritage				X	
Service quality					
Building envelope quality					X
Conversion reliability					X
Spatial efficiency	X				X
Easiness of dismantling and recycle	X				X
Economic performance					
Life cycle costs	X		X (i.d.)	X	X
Long-term value stability				X	
Process quality					
Integrated design process				X	X
Construction process impact					X
Commissioning					X

Note: i.d. – in development

This analysis showed that despite of all efforts that have been performed regarding the harmonization of sustainable construction language, there are still significant differences between the key indicators of each initiative. However, it was possible to verify that there are some indicators that are selected by most of the initiatives.

4 KEY INDICADORS SELECTED

The total number of indicators selected by the four initiatives analysed was forty one. However, it was verified that twenty seven of these were selected only by one of the initiatives. Table 3 presents the list of indicators selected by at least three initiatives. The indicators presented in Table 3 were chosen to the study, with the exception of “Public transportation system”. This indicator will not be studied since their performance cannot be changed by design options and its assessment is beyond the building boundaries.

Table 3. Indicators selected by at least three initiatives.

INDICATOR	NUMBER OF SELECTIONS
Non-renewable primary energy	5
Water consumption	5
Indoor air quality	5
GHG emissions	4
Lightning	4
Thermal comfort	4
Life cycle costs	4
Public transportation system	3
Renewable primary energy	3
Acoustic comfort	3

As exposed, the fact that an indicator was frequently included in different BSA tools or initiatives is a good indication of its importance. However, excluding other indicators, only because they are not usually assessed can led to an exclusion of important impacts. In order to understand the importance and significance of each indicator referred in Table 2, a bibliographic revision of the correspondent impacts were performed.

Besides this analysis, the selection of indicators was performed considering the following aspects:

- All indicators with a subjective assessment were excluded;
- All indicators whose performance cannot be changed by design options or whose assessment goes beyond the building boundaries were excluded;
- All indicators whose performance was difficult to translate into economic terms were excluded.

Additionally, it was intended that the key indicators list is broad enough to include the mainly sustainable buildings impacts, but also concise enough in order to make the assessment practicable.

There are some indicators which impacts were considered important but that were not chosen to the study because the difference of costs between the different associated building practices was difficult to assess. These indicators were: soil sealing, undisturbed areas contamination, conversion reliability, easiness of dismantling and recycle and spatial efficiency.

Additionally to the indicators presented in Table , ten additional indicators were selected with less than 3 selections in the methodologies. These ten indicators were associated with two categories, materials and wastes, process quality. In order to understand the importance of these indicators, a brief bibliographic review of these two categories is presented below.

4.1 *Materials and Wastes*

The building sector is responsible for the extraction of 24% of raw materials on Earth. Additionally, the extraction, processing, transport and application of building materials are responsible for the consumption of great amounts of energy (EC, 2011). Therefore, the quantity and type of materials used in construction have a huge influence on the building environmental impacts (Krausmann et al., 2009).

The importance of these impacts in buildings sustainability assessment is undeniable. However, sometimes, these impacts were not assessed in BSA tools due to the complexity associated with their assessment. When considered, the building materials environmental impacts were assessed through a Life Cycle Analysis (LCA). LCA is a methodology that assesses the environmental impacts of a product, system or material during all of their life cycle (Rincón et al., 2013). Through an LCA it is possible to quantify the following indicators: materials embodied energy, ozone depletion potential, acidification potential, eutrophication potential and photochemical oxidation potential.

The building sector is also responsible for the production of 40% of the world solid waste (UNEP, 2011). So, the quantity of waste produced by a building both in the construction and in the operation phase is also a very important indicator in the building sustainability assessment.

4.2 *Process Quality*

The process quality category is related with the measures that could be taken for the proper development of the building construction and management process.

An emergent theme related with the sustainable buildings is the Integrated Design Process (IDP). As already stated, the sustainable construction is a broadly and multidisciplinary theme, that encompasses the management and integration of different kind of information. Besides, some of the aspects related with this concept should be analysed in the early stages of design. These challenges are forcing the building professionals to interact among each other in order to find positive synergies among different subjects. Therefore it is necessary to create a process that connects these different subjects (Mora et al., 2011).

The Integrated Design Process is the process that intends to fulfil this need. It helps the client and the designer to select optimal cost solutions. The IDP consists in an integrated approach that provides more positive results and high-performance levels (Larsson, 2009). This process includes the active and continued participation of all building stakeholders (Mora et al., 2011). The basic principle of IDP is that the later a sustainable related measure is applied, the bigger the costs and the lower the intervention possibilities.

Another process that should be considered in order to obtain a proper building management is commissioning. Commissioning is a systematic and documented process that ensures that the operational needs of the owner are achieved, that the system operate efficiently and that the building workers and users receive education that ensures the proper operation of the building systems. The commissioning should occur across all building stages since the predesign till the operation phase.

The building systems are one of the main contributors to the building energy consumption. Therefore, an adequate management of these systems will carry significant economic savings. A building with commissioning has operational costs between 8% to 20% inferiors than a building without this process (GSA, 2005).

4.3 *Key Indicators Selected*

Due to their importance regarding sustainable buildings, nineteen indicators related with the three main sustainability dimensions (environment, society and economy) were chosen.
The indicators selected were presented in Table 4.

Table 4. Sustainability indicators selected.

DIMENSION	CATEGORIES	SELECTED INDICATORS
ENVIRONMENT	Energy and Emissions	Non-renewable primary energy
		Renewable primary energy
		Green House Gases emissions
	Water	Water consumption
	Materials and Waste	Materials embodied energy
		Ozone depletion potential
		Acidification potential
		Eutrophication potential
		Photochemical oxidation potential
		Reused and recycled materials
		Responsible sourcing materials
		Waste production
SOCIETY	Users health and comfort	Indoor air quality
		Lightning
		Thermal comfort
		Acoustic comfort
	Process quality	Integrated design project
		Commissioning
ECONOMY	Economy	Life Cycle Costs

5 CONCLUSIONS

Through the revision of the results obtained in some European initiates, developed with the goal of select sustainability key indicators, was possible to observe that despite all the efforts, there are still some different between the lists of key indicators developed. However it was also possible to observe that there are some indicators whose selection is consensual among different BSA tools.

However, when selecting a set of indicators to assess sustainability, it is important to analyse the most significant buildings impacts and the socio cultural context.

The work presented in the paper selects a set of indicators that will be used in the cost-benefit analysis to sustainable construction. Due to the goal of the work, some specificities were applied in the selection of indicators. Nineteen indicators were selected and distributed across the three sustainability dimensions, environment, society and economy.

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Chapter 7

Renovation and Retrofitting

Renovation project / sustainable rehabilitation center headquarters district of Porto - Portugal.

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ABSTRACT: The existing building of the Port District Centre will be undergoing redevelopment and is intended, in their entirety, the administrative services. This paper is a summary of the draft prepared under the "remodeling / rehabilitation constructive Headquarters of the District Centre Port", Portugal. The study presented below proposes a set of architectural solutions economically viable, through the principle of cost / benefit which analyzed, among others, the strength and durability of the structure, infrastructure and materials, with the cornerstones sustainability in construction the well-being of the occupants, the possibility of integration of renewable energy as well as the reorganization of landscaped outdoor spaces. This contributes to improve CO_2 absorption by plants while providing an alternative use of green areas as a social meeting point.

1 INTRODUCTION: PREVIOUS CONSIDERATIONS

Project Renewal Headquarters Social Security Port had the following objectives: Reshaping work areas and social areas, including the area Canteen and Bar; ensure accessibility for people with disabilities, particularly in terms of IS; Replace water and wastewater infrastructure existing and proposed mechanisms to reduce consumption; study constructive solutions thermally efficient exterior walls; Replace existing frames by another efficient; provide natural lighting in workspaces, including the design of structures removable for greater flexibility spaces.To meet the above objectives and considering that building form and orientation can not be changed, the following strategies were study in order to improve termal comfort conditions, in a sustainable approach:

a) Heat avoidance strategies through shading and filtering devices for the building's facades. Heat gains through windows can be very significant, as conventional windows offers little resistance to radiant heat transfer. This study proposes the rehabilitation of the existing south-east and south-west blades, as weel as a new double-skin south façade.

b) Heat dissipation strategies maximising heat losses, through natural ventilation process in the double skin façade, preventing overheating in summer and promoting solar gains in winter;

c) Study of the environmental characteristics of various architectural solutions, aiming to implement design strategies that provide better working conditions, for example in luminal and natural ventilation, according to the orientation of the building and optimizing comfort without wasting energy and of water.

d) Study of the proper location of insulation to increase the thermal inertia of the building, protecting it from heat gains during summer and decreasing heat loss in winter. This study proposes the external insulation in the opaque walls, in order to prevent thermal bridges;

e) The use of the rooftop for integration of an urban wind turbine as a positive contribution to reducing greenhouse gas emissions resulting from energy consumption.

2 SUSTAINABLE DESIGN STRATEGIES IN OFFICE BUILDINGS

2.1 *Passive Systems/ Energetic efficiency*

The identity of an area should be enhanced especially in terms of cultural heritage and preservation of the positive aspects of existing built environments. Most of passive techniques are generally simple to apply requiring a relatively low budget investment and low maintenance costs. Thus we believe refurbishment represents an excelent oportunity to introduce sustainable strategies, already aplied in most part of new buildings.

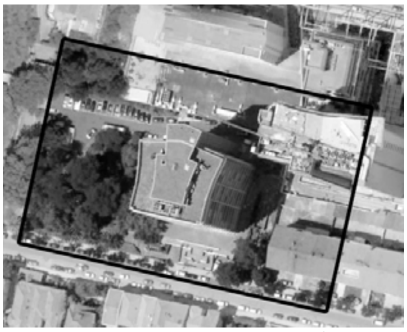

Figure 1. Urban integration of the building site using a climate software

Energy consumption in buildings is related with three importante factors: population growth, economic development and technological progress and represents 40% of total energy in U.E. This means they consume more energy than any other sector of europeen economic system. On another hand, developed countries should assume responsability to diminuish the long term impact of energy consumption in buildings. This measure represents an opportunity to adapt and transform old buildings or ones that no longer correspond to the actual needs, in terms of termal, visual or environmental comfort.

The building in question has 13 floors above ground and a prime location, free of obstructions guidelines East, South, West and North. Obstructions in the Northeast direction.

The annual solar path allows to understand the good exposure of the building, optimizing energy savings and, simultaneously, providing comfortable environments. The existing plant, close to a square shape, presents an excellent "shape factor", which allows a good balance in thermal exchanges control along the day and the year.

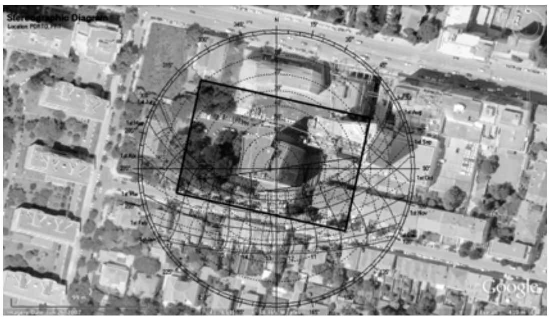

Figure 2. Anual solar trajectory

Figure 3. Optimized solar orientation

The largest proportion of a building’s solar heat gains comes through its glazed areas in the façades.

Heat gains through windows can be very significant, as conventional windows offers little resistance to radiant heat transfer. So, the choice of window’s glazing type is very important to calculate the percentage of solar penetration into the building. Accordingly to the project, the existing windows will be replaced by double-glazed windows with Low-Emissivity glazing. This type of glass can be almost opaque to infra-red radiation, reducing the solar transmission by more than 50%.

Another strategie to overcome the solar gains is the opaque envelope shading that should be used on the surfaces that receive most solar radiation caused by the low angle of the early morning and afternoon sun. Since the building already has shading systems in the east and in the west façades it is proposed to recovery and maintenance. However, it appears that the south façade has no protection, so this proposal envisages a solution in metallic structure for fixing a curtain wall glazing.

The best building orientation to reduce solar heat gains is the main façade facing south. Des pite this, it’s not shading protected. The project predicts a double skin façade wall glazed, that allows two overheating prevention passive cooling strategies:

Summer:

The double skin façade will be provided with operating controls that must remain open in Summer time, allowing the stack effect between façades. This type of ventilation generates a vertical pressure difference that allows warm air to rise, flowing out the top of the openings, and so, the cool air will penetrate the building at ground levels.This cooling technique helps to prevent overheating. The skin façade also contributes to retain the majority part of the heat gains and the other part is easily controlable by horizontal overhangs.

Winter:

The operating controls should be closed in Winter, ao that the heating caused by incident radiation on the double skin surface can provide heat gains into the air gap that are transferred into the building. As already mentioned, overhangs or other shading devices will allow the positive benefits of sun in the interior space work reducing the use of mechanichal devices to achieve comfort.

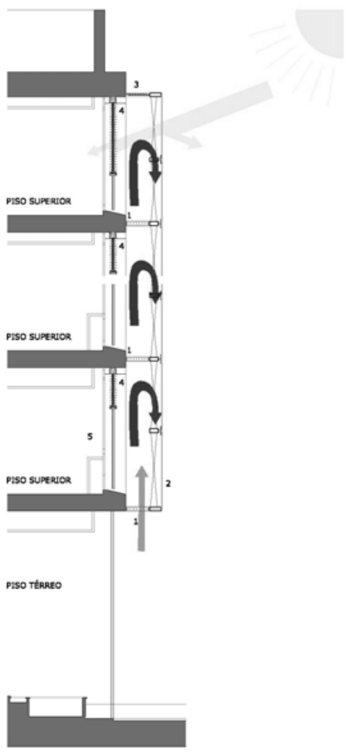

Figure 4. Heat gains in Winter

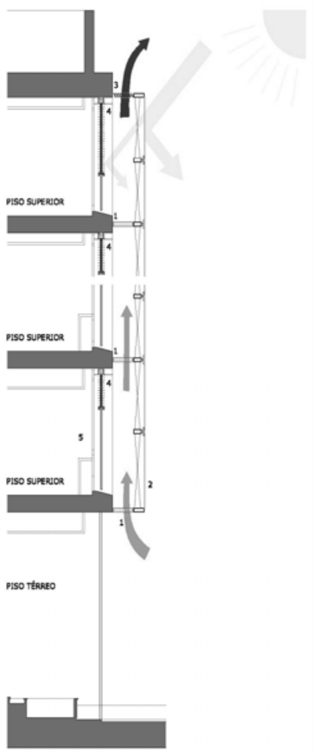

Figure 5. Heat losses in summer

LEGEND:
1 - Floor Technician anodized aluminum railing. Air intake.
2 - Laminated glass with low emissivity (serigraphy) fixed metal brackets type "spiders" steel.
3 - Directional shading, with the possibility of complete closure.
4 - Exterior shutters blades collect rotatable aluminum.
5 - Frames to replace existing window frames with thermal double glazing.

Figure 6. Photomontage with blades recovered

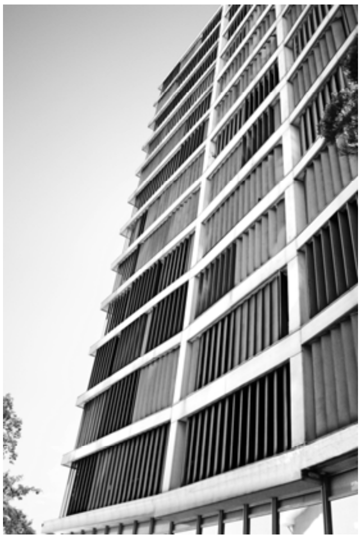

Figure 7. Simulation of proposed double skin façade

During the 20th century attempts and efforts were made to combine environmental parameters and physiological variables in developing an effective model of heat stress index. The existing indexes can be divided into two main categories: Effective temperature (ET) based in metereological parameters (e.g. ambient temperature, wet-bulb temperature) and rational heat scales, wich include a combination of environmental and physiological parameters (e.g. radiative and convective heat transfer, evaporative capacity of the environment and metabolic heat production).

These concepts have been transposed into software - ECOTECT, conceived by Professer Andrew J. Marsh of University of Cardiff, in the U.K. and integrate a tridimentional scale with a large spectrum of analisys and simulations of environmental comfort and energetic indicators.

Annual temperature in Porto is characterized by a cold winter in a range between 5º e os 15ºC and a good summer temperature, in average not above 30ºC. Fig 12 shows that between April and October O'Porto climat is pratically neutral towards comfort temperature (18º-26º).

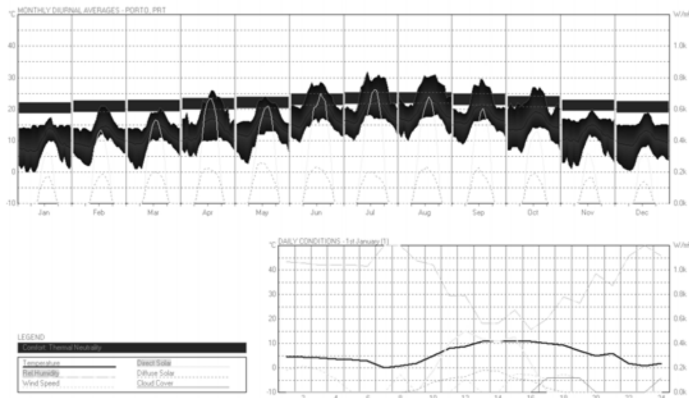

Figure 8. Study of monthly average temperatures through the year and Comfort zone

2.2 *Wind energy*

"The microgeneration, ie the production of electricity through small-scale installations using renewable or conversion processes for high efficiency (microturbines, micro-wind turbines, photovoltaic panels, small hydro, cogeneration) is at the center of a revolution that urges investing and it will shake the classic centralized model of production and distribution of electrical systems of most European countries. It is a change caused by the expansion of renewable energies, the emergence of a new generation of consumers who are at the same time, energy producers, the introduction of new information and communication technologies in low voltage networks that bind small equipment and a new concept for managing electrical networks, adapted to the requirements of decentralization "(Source: INESC, PORTO, 2009).

Wind power as a generation source has specific characteristics including variability, favourable economics and, above all, abundance and environmental benefits. A unit of wind-produced electricity displaces one generated from coal or gas, so reducing CO_2 emissions.

The installation of turbine 18 WES (80 kW) can be performed by connecting to the network minigeneration. To this end, the contracted power has to be at least twice the power generator. The sale, according to DL34/2011 is also limited by the energy delivered to the grid. The energy consumed in the facility use should be less than 50% of the energy produced by the unit mini-produção being taken by reference to the relationship between the energy produced and consumed in the previous year, for installations in operation for more than a year as is the present case.

2.2.1. *Evaluation of the potential sustainability of the solution from the viewpoint of reducing consumption*

In addition to the concerns and commitments that Portugal is in the energy and environment there, from the standpoint of economic enterprises, foundations increasingly visible to a deve lopment in the renewable energy market. We see that the cost of electricity, inseparable from the price of oil has risen consistently in recent years. Additionally relates that made a comparative study between the average monthly consumption of a family with contracted power of 6.9 KVA which is in the order of 156 kWh ie 1,872 kWh / year, which equates to 69.4 families. Also, in comparative terms, we calculated the number of lamps 7W, lit 10 hours a day, for a year, which would give 5,088 bulbs equivalent to the operation of this turbine urban.

2.2.2. *Economic analisys and integrated value model*

The economic analysis of projects provides financial justification for investment decisions and allows identifying the benefits and expected costs of a given project. This study was based in the important relation between User-value, net generation and the cost of electricity in the early phases and explains the advantage of a well structured project through time (fig 9).

The time required for the benefit equals the sum of initial investment amount will vary from case to case depending on:
- From the turbine power - usually the cost/benefit ratio is better for devices with higher power;
- Of the wind conditions of the site, ie, the more wind higher annual production;
- The price at which it sells the energy produced to the network;
- The amount of investment;
- The degree of utilization of the energy produced.

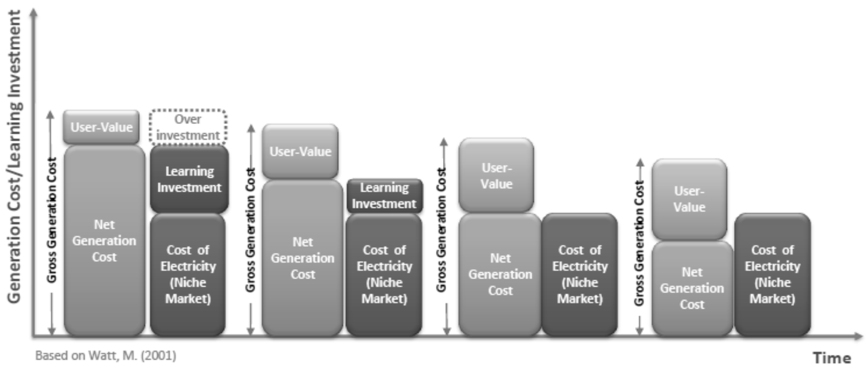

Figure 9 – Integrated value model, according to Watt, M.

In practice, the energy produced annually by the turbines is: WES18 @ 6.5 m / s ± = 193,000 kWh - 30m or 40m tower.

Hence, the energy consumed for installing a plug in minigeneration year will have to be greater than 50% of the values stated above.

The connection will have a MINI compensation + / € -0.20 / kWh which gives: WES18 @ 6.5 m / s = + - € 38,600 / year.

The turbine cost about (subject to validation onsite and including maintenance costs):
WES18 - € 220,000 - € 260,000 (simple payback of approximately 6 years).

2.3 *Thermal design according RSECE*

To ensure comfort conditions in different areas of the building and some constraints of architecture, it is recommended the installation of HVAC (Heating, Ventilation and Air Conditioning) in the building through a centralized solution.

Thus, the Central scheduled for the building produce, simultaneously, cold water and hot water system (4 pipe) through 2 Chiller's Heat Pump Air / Water, with a recovery system to put the cover building.

Given the airflows involved in climate spaces will choose whenever energetically justified by system energy saving type "freecooling" or "free cooling", seize the favorable conditions of the outside air and / or inside (to different enthalpies exterior and interior).

Thus, by varying the amount of fresh air / return, it is possible to ensure environmental conditions with minimal thermal costs.

In all situations where the use of systems of "free-cooling" is not viable, will use systems with heat recovery (using recuperators or static type systems "run around coil"), taking advantage of the heat balance between the air and extract air to inflate the building for renewal.

2.4 *Refurbishment full of work areas and water and wastewater infrastructure*

With a view to improving the preliminary Study submitted to the competition and under the laws in force, we propose a new design of IS Floor type.

The solution to adopt for the installation is specific operation of the facility. It is intended that the drinking water consumption is reduced in the order of 30% compared to normal values.

As measures for minimizing consumption will have the installation of low consumption toilets (4-6 liter controlled discharge), installation of timed taps, installation of control systems for automatic discharge in urinals (infrared, magnetic sensors and liquid systems, use of rainwater for toilets and urinals to 100%

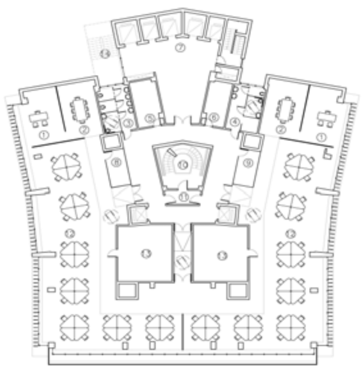

Figure 10. Main floor: functional distribution

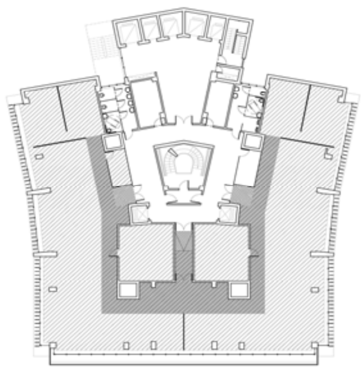

Figure 11. Main floor: Floor finishes

Floor finishes legend:
- Floor technician, h= 12 cm
- Existing pavement recovered
- Internal circulation zone

The level of hydraulic distribution of cold water and hot water conditions are created to save energy, using for supplying cold water and hot water flow variable electro groups, which allows the adjustment of the actual energy consumption thermal needs of the spaces in each moment.

3 DESIGN RECOMENDATIONS

General definition of the construction processes and the nature of the materials and equipment most significant, having remarkable thermal loads and the impact of which involves a set of strategies to define.

Decision to perform the intervention in the building, in order to maximize the use of existing resources; resolution of the problems detected in the phase of analysis and diagnosis; Definition of the best solutions in terms of quality / durability / costs as well as the versatility of the organization space for future use.

The proper location of insulation may increase the thermal inertia of the building, protecting it from heat gains during summer, and decreasing the rates of heat loss in winter; For example, the application of thermal insulation which, over the life cycle of the building, provides energy savings about 150 times the energy used in its production;

During the construction phase, reduce the impact of noise in the course of work;

Reduce the environmental impact, preventing air pollution and soil degradation and ecological characteristics;

Choice of sustainable materials, such as wood from forests replanted with environmental certificates proving the origin, composition and environmental impact of the material;

Choice of local materials or provenance exceeding 100km, favoring not only the local and national economy, but also to reduce the ecological footprint of the material affects the transport;

Integration of recycled materials or recycled in the large percentage of its composition are examples that some aluminum window frames or floors cluster of rubber;

Choice of materials free of VOCs, heavy metals (lead, mercury, cadmium and chromium VI) often present in paints and varnishes.

Reduce the production of construction waste, making the separation of the RCD;

Implementation of systems management and monitoring of energy and water consumption;

At the stage of Use / Maintenance should be done training for users on the consumption of resources (energy, water and materials);

Ensure the quality of the indoor environment through proper use of ventilation mechanisms;

Develop a manual of use and maintenance, as an identity of the building;

In terms of renewable energy, the urban WES 18 system allows the use of penetration of wind energy up to 100% without the need for use of system power dissipation in excess.

In addition to the studies presented in relation to bioclimatic strategies, energy management and efficient use of water, there are systems sustainability assessment adapted to the Portuguese reality, namely sbTool-PT.

We propose to conduct a well, which should focus on the criteria that are applicable and appropriate to understand the case study, with regard to its relationship with the environment considering the three dimensions of sustainability - The Social, the Environmental and the Economy.

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Strategies for regeneration of widespread building heritage in Italy.

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ABSTRACT: Widespread building heritage in Italy, especially that of historical cities, is mainly composed of diffused and small scale private property. This stock, while constituting an important resource, contains many critical elements. An important question regards the achievement of the standards for buildings energy performance, often unsuitable than required by law. It is also necessary redefine the characteristics of users, that due to the current economic crisis has gradually impoverished to be placed in a "gray area" of the population capable of producing economic resources but unable to support the costs of upgrading the energy efficiency.
Among the possible solutions, trying to find new ways of thinking to solve the gap between the need to take action and scarcity of financial resources, it is important reflecting about the concept of a building no longer understood as a consumer of energy, but as a producer of the same. Because of the development of technical solutions for the housing, more and more performing in terms of thermal comfort, has increased the possibility to produce energy in excess of what is needed for the conduction of the building, potentially sealable in the market. This surplus, on which improvements are possible, is the key to completely change the concept that revolves around the management of residential buildings.
In this regard it is necessary to look at the issue from a technical managerial and economic point, taking into consideration the technology used and financial and economic instruments for private sector housing.

1 INTRODUCTION

Widespread residential building in Italy, especially that in the major centres of population, is characterised by a significant fragmentation in reference to the period of construction, the construction technologies employed, and its state of conservation. We are faced with a group of heterogeneous subjects that do not lend themselves to classification.

80% of this heritage is privately owned; the activities it is subject to are characterised by being carried out in a timely manner, often to solve problems inherent in the use of the accommodation in which the owner lives. These interventions can be defined using the term "widespread constructive renovation", an activity that is often performed independently and without coordination, employing small builders who are often not particularly attentive to the quality of the interventions they carry out.

This fragmentation in property also creates a problem when it comes to gathering information on the extent of the stock in general and the conditions of individual buildings. This problem is compounded by the historic and consolidated resistance of the small private owner to provide information about the condition of the property in which they live. The lack of a census that might produce accurate, comparable and measurable data is one of the reasons why identifying possible intervention strategies is extremely complex.

While in public housing or that belonging to large private owners there is the possibility of using analytical methods aimed at defining its physical condition and usage in order to predict subsequent interventions, when it comes to the fragmented building stock dispersed among small owners, this phase is entrusted to the (often scarce or non-existent) technical and cultural capacities of the individual owners.

This situation has been compounded over the past ten years by the development of the environmental emergency, with the consequent increase in the level of attention to the limited functionality of buildings with respect to performance requirements for energy efficiency.

2 THE CHARACTERISTICS OF CURRENT HOUSING STOCK

The extreme heterogeneity of the current housing stock complicates the definition of the subject which is to be acted on. As a starting point, within this very complex framework, it is therefore necessary to try to determine if there is a lowest common denominator that is shared by the widespread residential housing stock despite its heterogeneity. This operation is possible taking into account different aspects, which have to do not only with the intrinsic conditions of the buildings, but also with the relationship between the building and its users. These characteristics can be summarised in the following:

1) Fragmentation as regards ownership. The CENSIS data relating to the conditions of the built heritage in Italy indicate that about 80% of the population owns its principal residence, that which is devoted to the carrying out of family life. This fragmentation makes it very difficult to intervene in a coordinated manner even as regards interventions to be performed on a single building, insofar as the client base potentially interested in improving the performance of their housing unit is fragmented within the building itself.
2) Characteristics of resident users. Housing currently used as private property is traditionally the preserve of the middle and lower middle classes. This class is currently in a state of great distress due to the economic crisis that has progressively undermined their economic potential, to the extent of being placed at the edge of a “grey area” of the population, capable of producing income but unable to bear the costs of energy efficiency upgrading. This section of society, although with differences of income, cultural level and general living conditions, is characterised by a set of common and critical behaviours as regards the demand for energy enhancement and improvement of the built heritage. The typical modus operandi of the small private owner is that of not showing any interest (for as long as possible) in the quality of the public areas but rather being interested only in the individual portion of the building they own.
3) Conditions of widespread degradation of the built in relation to some parts of the building or the whole building system. The need to renew the existing has mainly to do with the need to redevelop the building envelope (roof and façade), considering both the level of generic and energy degradation.
4) Low performance in terms of energy. Because of the structural characteristics, which date back to a highly speculative period for Italian residential building (from immediately after the World War II to the early ‘80s), most current buildings in which the Italian middle and lower middle classes live can be identified in categories of energy classification that are mediocre. (This is with reference the certification criteria currently used which have become more widespread recently thanks to the inclusion of energy performance certificates among the documents required to be submitted in the case of sale of a property). The need to redevelop, also and especially in terms of energy, is opposed by the ongoing economic crisis which has had a very serious impact on the construction sector in general.

3 THE ECONOMIC CRISIS AND THE DEMAND FOR REDEVELOPMENT

3.1 *The crisis of the middle class and the crisis in the construction sector*

We are therefore faced with a very complex, very extensive stock, and one that contains profound critical elements, affecting both the intrinsic conditions of the built and the relationship between these conditions and the characteristics of resident users.

The reasons for the need to redevelop the current housing stock are to be found not only in the desire to pursue better energy standards or improve the quality of the urban environment, but also on the fact that this constitutes the primary residence of the middle class. The operations carried out upon it represent a considerable economic investment, involving the interests of small and medium enterprises and everything that revolves around that micro entrepreneurship that has been for many years an important lever for the growth and economic development of the country.

The need to make the most of and redevelop the current housing stock intersects therefore with the need to find ways to intervene in an area that is currently in deep crisis.

This severe crisis is highlighted by the private market for house sales, which is currently in a phase of steep decline compared to the previous five years. (From data from the Agenzia del Territorio - the Land Agency - the market, which had been shrinking since 2006, reached a minimum in 2012 in terms of the number of property transactions entered into). Therefore, as a result, there is a crisis in the businesses connected with the restructuring and management of houses.

3.2 *The demand for energy production in current building*

At the same time, in contrast to the tendency of the past few years, thanks to the existence of incentive mechanisms, there is a growing interest on the part of the small private owner in installing private solar collection plant, in an attempt to become independent of the national energy distribution networks.

This trend is also encouraged by the recent amendments to the regulations of condominiums, the establishment of which in Italy is compulsory for buildings divided into more than eight residential units and which, with the help of a specialist technician (building manager), takes joint decisions regarding the management of the building.

The regulations regarding condominiums have recently been reformed by Law 220/11 12/2011, published about a year later in the Official Gazette on 17/12/2012 and in force since 18/06/2013. One of the reforms envisaged in the bill provides for the production of energy from renewable sources, which is simplified in favour of the individual condominium resident who wishes to set up their own system of energy production in areas of their own property but also in reference to the common areas (such as the roof area) without needing any authorisation from the condominium which, though, can still dictate some rules. An interest in energy production is therefore considered by the legislator to be pursuable and desirable. It remains to be seen how this demand will be resolved, and through which means it is possible to introduce the concept of energy production on a large scale.

On currently existing housing stock therefore there exist two powerfully opposing demands. On the one hand the impoverishment of the lower middle and middle classes tends not to stimulate building operations (primarily sales and renovations), while, on the other hand, there is a tendency to seek to invest in the production and management of energy, operations that involve interventions on the building envelope.

The dispersal of information on the built and the fragmentation of property, however, can lead to a situation in which each unit decides with respect to its own demand for energy production, with all the consequent risks from operating in an autonomous, individual and uncoordinated way, with strongly individual choices that in the long run are likely to overlap with other individual choices and create disagreements.

Both aspects then, that relating to the lack of financial resources for the redevelopment and the one regarding the lack of coordination on information, deserve to be studied in depth and carefully.

4 FROM THE PRODUCTION OF ENERGY TO THE PRODUCTION OF ECONOMIC RESOURCES

4.1 *Energy self-sufficiency as an opportunity*

Energy-efficiency upgrading brings economic benefits in the medium and long term, but they require an initial investment to be made.

There is therefore a strong contrast between the limited economic resources available and the demand for energy-efficiency upgrading. Intervening on private property means, as mentioned before, using the resources of a social class, the middle class, which is currently in deep crisis.

Examining the practical possibilities in this regard means finding the meeting point between the needs of the small private client, who wants to save money and possibly produce energy without assuming the costs of an intervention in this sense, those of the manufacturers/installers of systems and components for energy savings, who wish to sell and install their products while maximising their earnings, and the possibilities offered by the energy market.

One possibility in this regard can be pursued by considering the building not just as a consumer of resources but as a possible producer of the same.

This possibility foresees that the management of the energy produced can be used not to the exclusive and immediate benefit of the owner, but exploited as an incentive to attract a potential investor with the technical and managerial skills necessary for the production and exploitation of the energy. The key phrase in this case is self-sustaining energy, a more and more attainable goal when we consider the extensive spread of homes at “almost zero” energy.

The ultimate goal is that of redeveloping in a sustainable way while taking into consideration the economic aspect, especially related to energy production linked to the introduction of solar and photovoltaic systems. At the basis of this type of intervention is the overturning of the common way of thinking about the home as something that consumes resources, focusing rather on the fact that, through the introduction of appropriate technologies, energy resources can be produced which, if managed in a correct way through the use of suitable management tools, can be transformed into opportunities to produce economic resources. These opportunities include the possibility of using the energy produced for the home and the services related to it, in order to create an organism that is as independent as possible from the point of energy support.

4.2 *Experiences in private construction. From incentives to market competitiveness*

The connection between the production of energy and economic resources has been supported by the growth of the sector related to the production of solar thermal and photovoltaic energy, supported by the policies put in place by the public administration to promote and support the production of energy from renewable sources. The summary “Statistical data on electric energy in Italy in 2011” by Terna highlights the enormous growth of the solar photovoltaic sector. Energy production increased by +499.2% (10.7 against 1.9 KWh) against the already considerable increase in 2010 (+177%). This production has been supported at state level by the incentive system which has evolved and expanded dramatically in the last ten years (Energy Account, Green Certificates, support fund financed by the Deposits and Loans Fund) in an attempt to make production from renewable sources competitive compared with the other traditional forms of energy production. Since 2005, five Energy Account (Conto Energia) measures have been issued, based on the system of direct incentives, which have strongly encouraged the production of energy from renewable sources with the aim of making it more affordable and competitive compared to traditional sources of energy production, reaching grid parity, which would allow the entry of renewable into a market system. This objective, close to being achieved but at the same time threatened by the economic downturn, is in a phase of transition and reorganisation; in the near future are foreseen the use of indirect incentives through tax deductions (with Law by Decree no. 63 of 4 June 2013 which allows for a deduction of up to 65% of the cost of energy improvements and building renovations) and the development of mechanisms to transfer energy directly without going through the traditional distribution network.

4.3 *Experiences in social housing. The funds and financial mechanisms for public and private entities*

On the concept of energy production, a number of experiments have been conducted in the social housing sector, therefore on a wealth of public property intended for a poorer user base. In this case, the main problem is finding the economic resources; the social housing sector is traditionally considered unprofitable by potential private investors, and also it cannot enjoy the same incentives earmarked mainly for the market private. In this case, therefore, one possible solution was the involvement of private financiers operating in the energy sector (ESCOs, Energy Service Companies, in particular), which through a range of technical and financial expertise are able to achieve an economic benefit from the production of energy in a building by improving the performance of the envelope and the installation of photovoltaic systems. The ESCOs gain economic benefits in the long term through the absorption of part of the savings achieved in the power bills. Through this mechanism it is possible to redevelop a building without passing the costs of this redevelopment on to the user.

The experiences in social housing therefore represent a possible key to being able to think in terms of energy production also on the built heritage made up of dispersed buildings.

This possibility, however, is pursuable also thanks to the fact that the assets of social housing have a single customer base, and it is therefore easier to conduct such operations since the decisions on how to operate are taken at the outset by a single owner. In the case of current building, this is not possible because of the fragmentation of the abovementioned property, which makes it difficult to coordinate the necessary interventions.

On a practical level there are some tools can be used that allow the financing of interventions to improve the performance of the building envelope and the promotion of energy production. These tools are aimed at both public and private operators, including the ESCOs, but also at small-business owners, and consist of investment funds at a low rate of interest such as those managed by the Deposits and Loans Fund.

One of the possible funding opportunities in Italy is the revolving Kyoto fund, available and operational since 16 March 2012. It can be used and combined with a number of incentives, such as those relating to the issuance of the Green Certificates, Third and Fourth Energy Accounts, and incentives for the production of electrical and thermal energy. The fund can be used by ESCOs but also by private subjects. At European level, it is worth recalling the European Energy Efficiency Fund (EEEF), related to the objectives of Europe 202020. In this case too, the possible recipients are the ESCOs.

5 THE COLLECTION AND DISSEMINATION OF INFORMATION FOR CURRENT BUILDING. CRITICAL POINTS AND BENEFITS

5.1 *From the building to the city. The advantages of intervening on a larger scale.*

Unlike what happens in social housing, which involves a stock of public buildings managed by a sole proprietor, as regards current building it is necessary to deal with the difficulties arising from the means, entirely individual and entrusted to individual owners, with which we reason on the theme of energy production.

If it is true that about 80% of Italians own their own home, this means that a single building is divided into separate parts belonging to individuals who think in completely different ways regarding what should be done.

Adding together the energy production of groups of houses instead of focusing on the efficiency of individual buildings is definitely more productive both in terms of the quantity of energy produced and of any power remaining as surplus being placed on the market. If it is this surplus that is to be the lever to move from the concept of the building as energy consumer (with the consequent demand for energy saving in its various forms), to a building that is as energetically independent as possible (aiming for the solution of the passive zero-energy consumption house), to, finally, the building as a producer of energy (thinking about the possibility of placing the produced energy on the market) and as a producer of economic resources, it is necessary to find the way to draw up collective strategies to enable this to happen. The conditions of the built heritage in Italy involve an urban core where concentrating on one building is not convenient precisely because it operates within a built context and not in an open space. The energy efficiency of a technological solution can be influenced by its relationship with other buildings, in terms of orientation, shadows, management issues or the shape of the building itself. The same house transported to an empty space with the right exposure could produce much more energy than if it were wedged into a system of very compactly built buildings; but at the same time the presence of very compactly built buildings, similar in terms of original constructive technology, and numerically significant, allows the making of more affordable choices.

5.2 *Operational problems and the role of the client*

Over the last ten years there have been various experiences in the collection of information for different reasons, but always related to the need to establish fixed points from which to start to make decisions about how to operate. The various experiences (from the Fascicolo del Fabbricato - the Building Dossier - on the risk of building collapse during emergencies, to the Energy Certification for the definition of energy performance during the period, still ongoing, of the environmental emergency) have had more or less satisfactory outcomes depending on how they were carried out and the moment from when their presence became mandatory in the life cycle of the building.

It is important to underline that imposing a collection of information on the conditions of the built conducted employing the help of a qualified technician and thus involving the payment of a fee, is not looked on kindly by the small owner as it is perceived as an additional tax to pay on the property; and this is increasingly true in the present historical period, characterised by a serious economic crisis that has been going on for several years and that has especially affected the lower middle and middle classes, the main client base in current and diffuse building.

The lever to ensure that the collection of information, the definition of possible strategies of intervention and the intervention itself on buildings is accepted, and then requested and desired by small private client, is that these operations are seen from a sustainable-economic point of view; not as a tax, therefore, but as an operation that not only does not cost anything, but that, at the same time, can be beneficial in economic terms. These benefits, in order to be understood in the right way, should have an immediate impact on the wallet of the small owner, and contemporarily a strongly perceptible fallout in terms of improving the quality of life collectively and individually.

The way to ensure that the small private owner takes care of public spaces rather than just individual ones within the four walls that define his/her own home, and is interested in intervening on the envelope of the building he/she owns and where he/she resides, is to make this intervention sustainable economically and with clearly perceptible benefits.

6. OPEN QUESTIONS AND CONCLUSIONS

6.1 *A model from the past for the city of the future. From the rural house to collective energy self-reliance for the smart city*

With reference to what was mentioned above about the model of energy self-sufficiency and self-reliance, it is important to stress that this is not a recent innovation. It refers to ancient models of managing residences, considered the only ones possible before the Industrial Revolution and the spread on a large scale of energy managed and distributed “from above” at a global level.

The idea of the building organism that tends towards energy self-sufficiency, freeing itself of the distribution networks in the area, thus constitutes a return to the past. The autonomous rural home of a few centuries ago produced the energy necessary for its own survival and that of the people who lived in it. With the advent of electricity the idea of a house capable of functioning independently gradually disappeared, and people began to rely on the energy distribution networks, which allowed an extension of electricity, gas and heating to all sections of the population, through facilities managed and served in a collective manner.

As a result of the typological and distributional transformations that have occurred in models of design and implementation, and the radical change in lifestyle of the population that has occurred rapidly in fairly recent times, the contemporary residence needs a quantity of energy and the means to manage the energy service that are radically different from those of the rural home of the past. A model of self-reliance which is similar to that of the past is inconceivable therefore, thinking of isolated organisms which operate autonomously for their own energy survival.

The big difference with the past, in fact, derives from the need to produce and manage energy autonomously while ensuring the connections and the exchange of information that are typical of the present historic period.

It is therefore necessary, and a viable possibility as regards which discussion and research are already taking place, the idea of self-producing and distributing energy from networks that no longer work according to a hierarchy running from top to bottom but rather according to a more linear and democratic logic, where everyone can be producers and contribute to supplying a distribution network managed "from below".

6.2 *The instruments for the development of small private clients. The voluntary sharing of information*

The terrain where probably there is more chance of the themes of self-production of and self-reliance on energy taking root and growing revolves around growing interest in the smart city. The key emerges from considering the demand for energy/economic production collectively, no longer being interested in the single building but in groups of houses arranged in blocks, sectors, larger groups than a single building. This involves, on the one hand, the possibility of producing energy in a more rational and efficient manner, but, on the other, it reveals critical elements both from the point of view of the management of the service and of the management of possible initiatives. Making choices on how to redevelop groups of buildings is a very complex step. Buildings that could potentially be part of the same network of energy production and conduct potentially very profitable operations, are unable to "talk" with each other because there are no instruments of any kind to establish communication networks between private property owners wishing to carry out a sustainable energy upgrading from an economic standpoint.

It this from this point of view that it is of fundamental importance that information on buildings is shared.

In order to ensure that the sharing might work, and be self-sustaining it is necessary to focus on two fundamental aspects:

- Ensuring a flow of independent and voluntary information
- Directing the distribution of information to the achievement of objectives which foresee not only an improvement in energy operations, but also the possibility of obtaining economic benefits.

The distribution networks of information on the city and its buildings have evolved and are reaching notable levels of innovation thanks to a growing interest in the smart city. The very recent development in the implementation of territorial maps through the use of multimedia information (from GIS to GPS devices to applications for mobile devices with augmented virtual reality) highlights the great interest in the dissemination of information that is useful and useable on a building and urban scale.

At the same time the explosion in mechanisms for the exchange of independent information relating to the most diverse issues, with the creation of portals and forums for sharing information which run from the scientific to the more strictly personal, highlights the great familiarity, regardless of the various cultural competences, as regards the use of the internet to share and disseminate information.

The idea of a platform for the exchange of independent information on the energy characteristics of a building, supplied by individual owners and shared on the internet at the level of condominium offers across-the-board advantages to everyone involved.

First and foremost this evolution is of interest to the client group as a condominium, which is given support to make the transition between a passive subject, which uses the urban spaces of the context in which it is inserted, to that of an active subject, which seeks in the same context means of cooperation and exchange in relation to the aim of energy production.

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Environmental impacts of elementary school building renovation: Comparative study

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ABSTRACT: This paper compares application of two different LCA (Life Cycle Assessment) tools for assessment of environmental impacts of the energy-efficient renovation of elementary school building located in Brno – Nový Lískovec, Czech Republic. The assessed renovation should be used as the example of energy-efficient and environmentally friendly building renovation in the Czech Republic. It is one of the case studies within the activities of IEA ECBCS Annex 56, Subtask C. The environmental assessment includes both the environmental impacts of the materials used for the renovation and environmental impacts of energy used for the operation of the building. Two different software tools Eco-Bat 4.0 and GaBi4 were used for environmental assessment of the school building. GaBi is a research tool for the life cycle assessment of various product systems. Eco-Bat is a tool designed specifically for the environmental assessment of buildings. Results obtained from both software tools are compared and discussed.

1 INTRODUCTION

IEA ECBCS Annex 56 project's goal is to develop methodology for cost-effective energy and carbon dioxide emissions optimization in building renovation. It is an international project involving institutions from 12 countries. Important part of the project is testing of the developed methodology on sample buildings located in several European countries. These buildings should be renovated with principles of the project in mind, using state-of-art materials and technical solutions, to significantly decrease the energy demands and environmental impacts. Elementary School Svážná, located in Brno – Nový Lískovec, Czech Republic, is one such building. Measures such as addition of thermal insulation on the building envelope, replacement of windows and doors, or installation of a new ventilation system were utilized to accomplish the set objectives. Use of renewable energy sources (photothermics and photovoltaics) is also expected, but (because of the lack of data) it is not taken into account in the presented paper.

Study presented by this paper is dealing with application of two different LCA (Life Cycle Assessment) tools for the preliminary assessment of environmental impacts of elementary school building's renovation: Eco-Bat 4.0 and GaBi4. Eco-Bat is a tool meant specifically for the environmental assessment of buildings. GaBi is more complex tool for the life cycle assessment of various product systems. The presented environmental assessment includes both the environmental impacts of the materials used for the renovation and environmental impacts of energy used for the operation of the building.

2 ELEMENTARY SCHOOL SVÁŽNÁ

Elementary School Svážná was opened in 1992. It consists of 8 interconnected blocks (see Figure 1). Total floor area of the buildings is 11,595 m^2. Currently the buildings are used not only by the elementary school, but also by local nursery school and university. Peak occupancy of the buildings is approx. 900 people – 500 children and 400 adults.

A - Main entrance and changing rooms

B, C, D, D1 - Classrooms

E - Cafeteria

F - Assembly hall

G - Gym

Figure 1. Aerial view of Elementary School Svážná. (*Google Inc, 2013*)

Because of the time of origin, the building`s do not fulfill current technical and hygienic requirements. There are large heat losses through the buildings envelope, the inner microclimate in the classes is substandard, etc. That's why a complex renovation is necessary. It will consist mainly of addition of thermal insulation to the buildings envelope, replacement of old (non-airtight) windows and doors. These structural changes will increase air tightness of the building envelope. Therefore changes in the ventilation system are required. Currently the school uses natural ventilation. During the renovation the designers consider addition of mechanical ventilation system. Assessment presented in this paper includes comparison of both ventilation methods. The amount of air required during the operation of the school was determined on the basis of Czech ordinance No. 410/2005 Col., to be 20 to 30 m^3·hod^{-1} per person (student). During times when the rooms are empty, the amount of fresh air required is decreased by 75 %. The rate of use of buildings was determined on the basis of energy audit (DEA s.r.o., 2012). Use of renewable energy sources (photovoltaic and photothermic systems) is also planned, but currently there are not enough information about this part of renovation, so they are not taken into account in this assessment. Table 1 shows comparison of thermal properties of the building envelope before and after renovation.

Table 1. Thermal properties of the building envelope.

Building envelope elements	Current state		Designed renovation	
	Construction	U-value [W/m^{2}k]	Added measure	U-value [W/m^{2}k]
Walls	Ceramic precast panels, reinforced concrete with 50 mm of polystyrene (EPS) insulation	0.74 – 1.21	220 mm of MW insulation	0.15
Doors and windows	Wooden and aluminium frames, single and double glazing	2.40 – 5.65	Plastic frames with triple glazing	1.40 (doors) 0.70 (win.)
Roofs	Reinforced concrete panels with 100 mm expanded polystyrene or mineral wool (MW)	0.42 – 0.43	250 mm of EPS insulation	0.11
Floor	20 - 50 mm of expanded polystyrene (EPS)	0.40 – 0.49	20 - 50 mm of EPS	0.41

The impacts the renovation will have on the overall energy consumption are shown in Figure 2 and Tab. 2. In dependence to chosen method of ventilation the overall energy consumption will be decreased approx. by 40 % (natural ventilation) or 74 % (mechanical ventilation) respectively. The requirements for the thermal energy for heating, which is supported by public steam and hot water pipelines of Heating Plants Brno will be reduced by up to 90 % (with use of mechanical ventilation). On the other hand, there will be increase in demand for electric energy (with use of mechanical ventilation), caused by the newly added technical equipment.

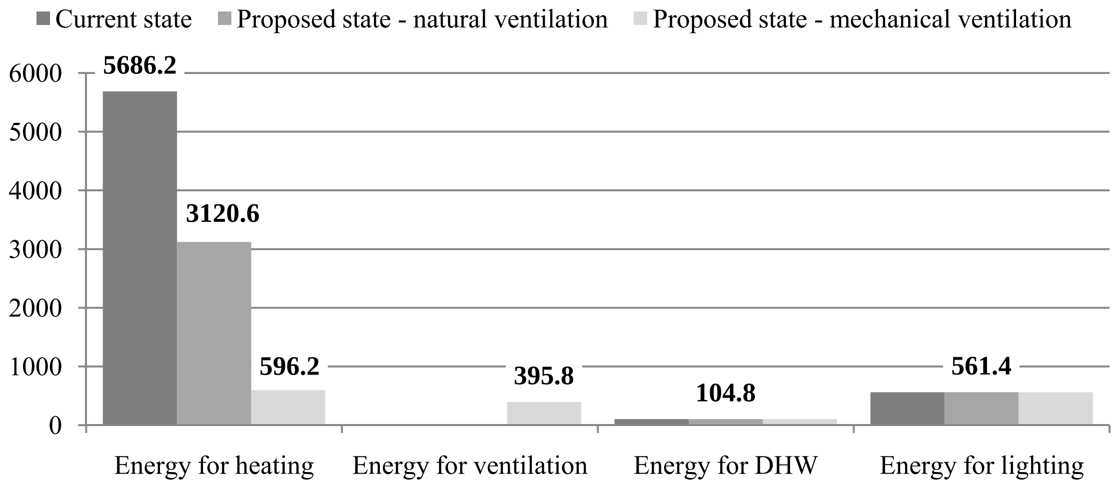


Figure 2. Energy consumption of Elementary School Svážná before and after renovation.

Table 2. Overall energy consumption of Elementary school Svážná.

Energy performance of building		Energy consumption before renovation [GJ·y^{-1}]	Energy consumption after renovation [GJ·y^{-1}]	Saving [%]	Energy savings [GJ·y^{-1}]
Energy for heating	Natural ventilation	5686.2	3120.6	45.1	2565.6
	Mechanical ventilation		596.2	89.5	5090.0
Total energy	Natural ventilation	6352.3	3786.8	40.4	2565.5
	Mechanical ventilation		1658.1	73.9	4696.2

3 USED TOOLS

Two different software tools, Eco-Bat 4.0 and GaBi4, were chosen for the preliminary assessment of the renovation. Both tools are based on the Life Cycle Assessment (LCA), as defined by international standards of ISO 14040 series. For both tools Ecoinvent database developed by Ecoinvent Centre in Switzerland was used as a main source of data.

Eco-Bat is a software tool developed by the Laboratory of Solar Energetics and Building Physics (LESBAT) in Switzerland. Its main purpose is evaluation of the impacts the life cycle of a building has on the environment. It is an easy to understand tool, that can be used by designers and civil engineers during the early design phases for assessment of their decisions about materials and technical solutions.

GaBi is a software tool for environmental assessment of various products and services. It is very complex tool with possibility of use of different databases and computational models. This is however the main disadvantage of this tool, as it is too complicated for common user (designer). It is developed by PE International in Germany.

3.1 *Eco-Bat 4.0*

As can be seen in Figure 3, Eco-Bat uses simple graphical interface for data insertion. The input data are divided into three parts, represented by three panels. The databases of materials, energy sources and technical systems included in these panels are taken from Swiss KBOB list (KBOB, 2012), which is based partially on the data from Ecoinvent 2.2 database, partially on the data from comparative studies conducted in Switzerland.

First panel (see Figure 3a) deals mainly with material composition of the building. Also, there are several other criteria used later in the computations – estimated lifespan of the building, type of the building (residential, administrative, etc.) or its floor area, etc.

Second panel (see Figure 3b) deals with the energy consumption of the building. Energy requirements for heating, cooling, domestic hot water and lighting have to be specified here. These also include information about the respective energy sources (e.g. waste incineration, steam-driven electricity generators) and their efficiency.

Third panel (see Figure 3c) of the data input concerns use of mechanical ventilation and renewable energy sources (e.g. heat pumps, photovoltaics or photothermics). In this part of data input there are only a few criteria to add into the assessment. The software will calculate the results by itself, based on floor area of the assessed building, area of the used photovoltaic or photothermic panels, etc.

Results of the assessment are shown (graphically as well as numerically (see Figure 3d) in four impact categories - Umwelt Belastung Punkte (UBP, ≈ Environmental Impact Points) (Favre & Citherlet, 2009), Non-Renewable Energy (NRE), Cumulative Energy Demand (CED) and Global Warming Potential (GWP). These categories and the computations of their results are fixed. (Favre & Citherlet, 2008)

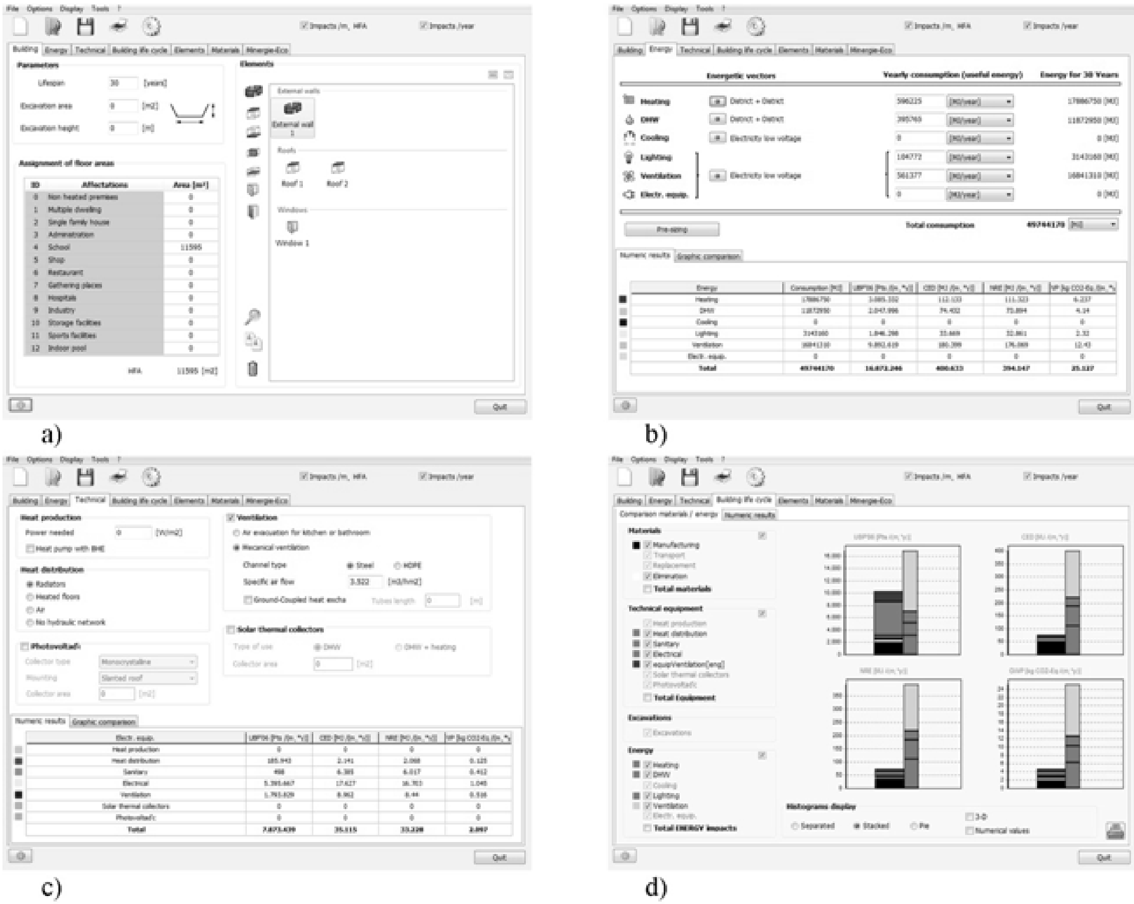
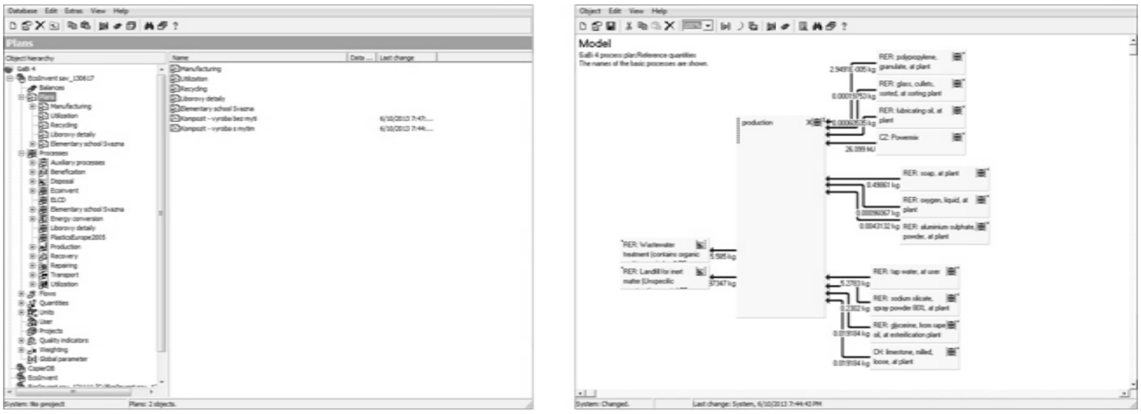


Figure 3. Eco-Bat interface. Input of data (a, b, c) and results of the assessment (d).

3.2 *GaBi4*

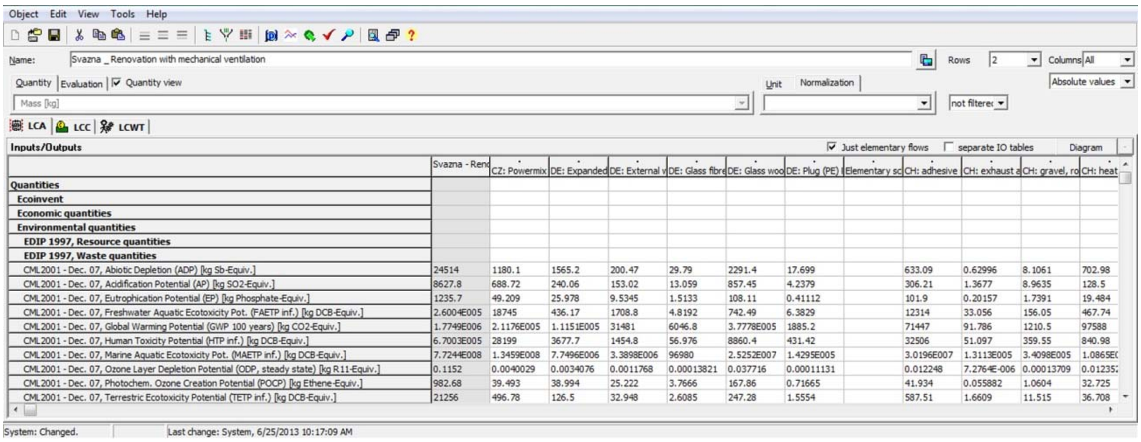
In comparison with Eco-Bat, GaBi uses more complicated interface (see Figure 4a) – there is no predefined structure of the assessed system. The model of the assessed system has to be created by connections of individual processes incorporated in the database of choice (see Figure 4b). These processes represent not only the materials and energies, but also manipulation with these (transportation, production processes, waste management, etc.).



a) b)

Figure 4. Main interface panel of GaBi (a) and an example of model created connecting different processes from the database (b).

Unlike Eco-Bat, GaBi can use many different characterization and normalization models (predefined or custom-created) for computation of the results. These models vary in use of different equations for assignment of environmental impacts caused by individual processes into different impact categories. As in Eco-Bat, the results can be shown graphically or numerically (see Figure 5).



Name: Svazna _ Renovation with mechanical ventilation

Inputs/Outputs	Svazna - Renc	CZ: Powermix	DE: Expanded	DE: External w	DE: Glass fibre	DE: Glass woo	DE: Plug (PE)	Elementary sc	CH: adhesive	CH: exhaust a	CH: gravel, ro	CH: heat
Quantities												
Ecoinvent												
Economic quantities												
Environmental quantities												
EDIP 1997, Resource quantities												
EDIP 1997, Waste quantities												
CML2001 - Dec. 07, Abiotic Depletion (ADP) [kg Sb-Equiv.]	24514	1180.1	1565.2	200.47	29.79	2291.4	17.699		633.09	0.62996	8.1061	702.98
CML2001 - Dec. 07, Acidification Potential (AP) [kg SO2-Equiv.]	8627.8	688.72	240.06	153.02	13.059	857.45	4.2379		306.21	1.3677	8.9635	128.5
CML2001 - Dec. 07, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1235.7	49.209	25.978	9.5345	1.5133	108.11	0.41112		101.9	0.20157	1.7391	19.484
CML2001 - Dec. 07, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	2.6004E005	18745	436.17	1708.8	4.8192	742.49	6.3829		12314	33.056	156.05	467.74
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	1.7749E006	2.1176E005	1.1151E005	31481	6046.8	3.7778E005	1885.2		71447	91.786	1210.5	97588
CML2001 - Dec. 07, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	6.7003E005	28199	3677.7	1454.8	56.976	8860.4	431.42		32506	51.097	359.55	840.98
CML2001 - Dec. 07, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	7.7244E008	1.3459E008	7.7496E006	3.3898E006	96980	2.5252E007	1.4295E005		3.0196E007	1.3113E005	3.4098E005	1.0865E(
CML2001 - Dec. 07, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	0.1152	0.0040029	0.0034076	0.0011768	0.00013821	0.037716	0.00011131		0.012248	7.2764E-006	0.00013709	0.01235:
CML2001 - Dec. 07, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	982.68	39.493	38.994	25.222	3.7666	167.86	0.71665		41.934	0.055882	1.0604	32.725
CML2001 - Dec. 07, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	21256	496.78	126.5	32.948	2.6085	247.28	1.5554		587.51	1.6609	11.515	36.708

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Figure 5. Numerical results of a sample assessment in GaBi.

4 THE ENVIRONMENTAL ASSESSMENT OF THE RENOVATION

The basis of the assessment with both tools was data mentioned in chapter 2. Because of the lack of specific data (e.g. data about energy sources) and the need for matching of the gathered data with processes included in used databases (internal database of Eco-Bat and Ecoinvent 2.0), lead to several simplifications. These include for example omitting of plastic plugs and reinforcing glass fibre mesh from the construction of the insulation layer in Eco-Bat, omitting of heating equipment or estimations of the emount of ventilation equipment in GaBi. There are also some general simplifications – e.g. transport of the materials as well as energy losses occurring in the supply network were not taken into account. Estimated lifespan of the renovation is 30 years.

The results of the assessment in Eco-Bat can be seen in Figure 6. Specific numerical results can be seen in Table 3. According to these results, both variants of the proposed renovation will be beneficial for the environment. For example amount of CO_2-equivalent emissions will decrease by 33.3 % if the natural ventilation will be used or up to 57.5 % with use of mechanical ventilation.

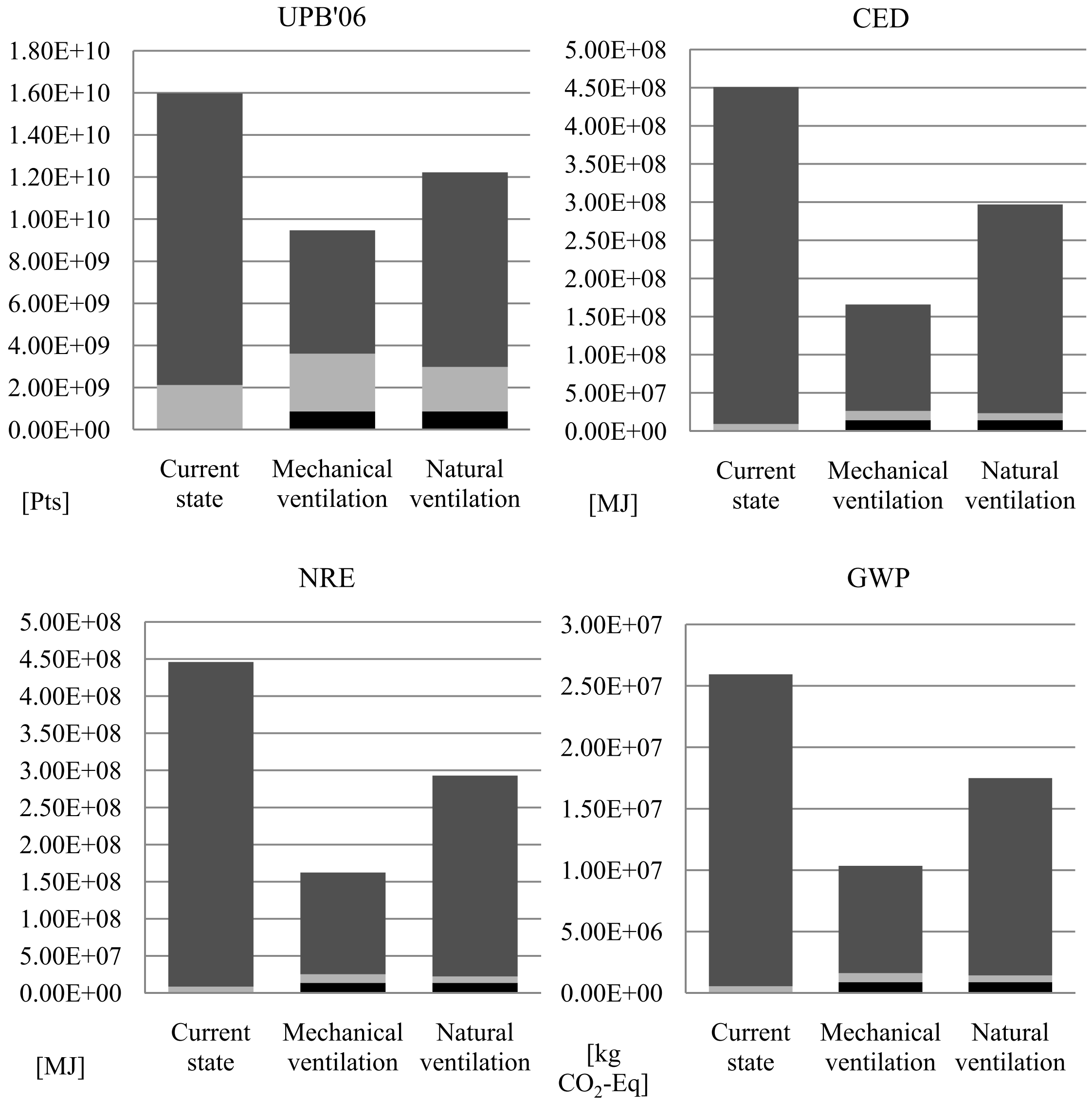

Figure 6. Graphical comparison of results from Eco-Bat. Black colour represents material, light grey use of technical equipment, dark grey energy consumption.

Table 3. Numerical comparison of results of the assessment in Eco-Bat.

School building	Lifespan	UBP'06	CED	NRE	GWP
	[years]	[Pts]	[MJ]	[MJ]	[kg CO_2-Eq]
Current state	30	15 979 956 144	450 699 606	445 980 459	25 945 316
Natural ventilation	30	12 225 621 136	297 039 803	292 939 413	17 489 777
Mechanical ventilation	30	9 471 600 716	165 757 128	162 250 296	10 349 593

In GaBi the Ecoinvent 2.0 database was used for creating the model of the renovation. Subsequently the characterization model CML2001 – Dec. 07 and normalization CML2001 – Dec. 07, EU25+3 were used for the evaluation of the model. The chosen characterization model has 10 impact categories into which the results are divided – see Table 4. Figure 7 shows detailed results of two chosen categories – Global Warming Potential and Marine Aquatic Ecotoxicity Potential.

Table 4. Comparison of the results of the assessment in GaBi.

Impact category	Unit	Current state	Natural ventilation	Mechanical ventilation
Abiotic Depletion	[kg Sb-Eq.]	198 825	143 653	85 146
Acidification Potential	[kg SO_2-Eq.]	46 301	38 822	36 833
Eutrophication Potential	[kg Phos.-Eq.]	5 875	4 729	3 543
Freshwater Aquatic Ecotox. Pot.	[kg DCB-Eq.]	510 425	683 390	950 608
Global Warming Potential	[kg CO_2-Eq.]	28 587 127	19 253 597	11 886 090
Human Toxicity Potential	[kg DCB-Eq.]	1 049 209	1 544 619	2 149 484
Marine Aquatic Ecotoxicity Pot.	[kg DCB-Eq.]	3 017 069 437	3 494 286 068	5 521 722 931
Ozone Layer Depletion Potential	[kg R11-Eq.]	3,154	1,887	0,597
Photochem. Ozone Creation Pot.	[kg Eth.-Eq.]	8 970	6 244	3 315
Terrestric Ecotoxicity Potential	[kg DCB-Eq.]	61 901	76 285	115 024

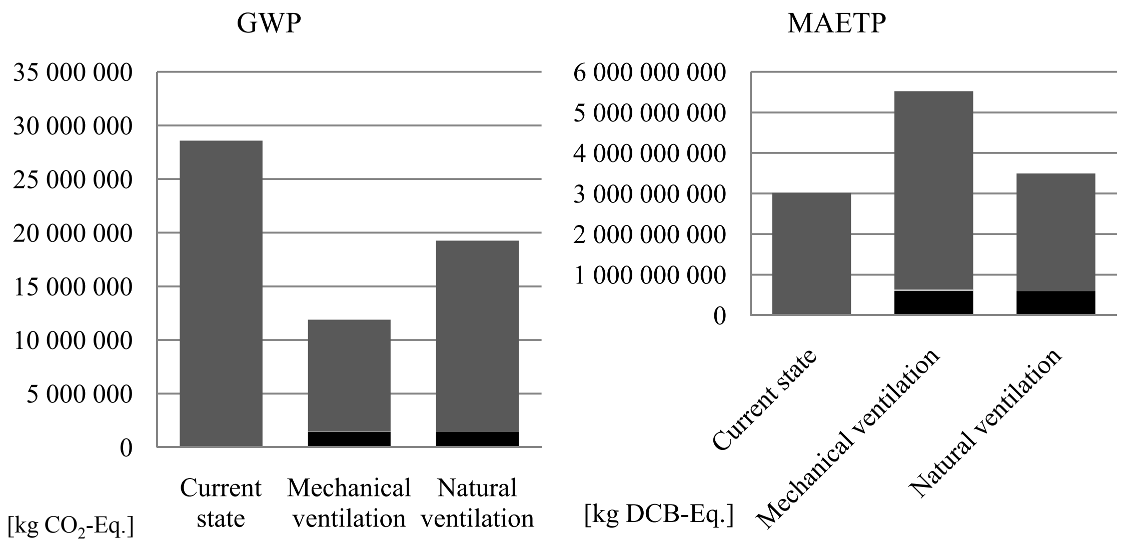

Figure 7. Graphical comparison of selected results from GaBi4. Global Warming Potential and Marine Aquatic Ecotoxicity Potential impact categories are shown. Black colour represents material, light grey use of technical equipment, dark grey energy consumption.

5 DISCUSSION

Eco-Bat and the chosen characterization model in GaBi use different impact categories for presentation of the results. There is only one impact category, which both tools have in common in the conducted assessment – Global Warming Potential. The results in this category differ by approximately 9 to 13 %. This difference has two main causes. First is the use of different characterization models for the assessment. Second is the requirement for simplifications, that had to be done, because of lack of data in databases, in combination with different approaches both tools have for insertion of data, especially about the technical equipment.

In general, the results obtained with use of Eco-Bat tool show, that the renovation of Elementary School Svážná will have positive impact on the environment – there are decreases in both energy consumption and carbon dioxide emissions.

In difference to the results received with Eco-Bat, when comparing results from GaBi, there are not only positive changes in the environmental impacts. One of the main causes of this is addition of new materials to the existing buildings (see Figure 7). The other is the change in the energy consumption of the school buildings (see Figure 2) – production of electric energy in Czech Republic, represented by the process ‘CZ: electricity, low voltage, at grid’ in the Ecoinvent 2.0 database, has much worse environmental impacts, than production of the thermal energy, represented by ‘CH: heat, at cogen 50kWe lean burn, allocation heat’ (see Table 5).

Table 5. Environmental impacts of production of 1 MJ of thermal and electric energy in chosen impact categories, according to GaBi4 with CML2001 – Dec. 07 characterization.

Impact category	Unit	Thermal energy	Electricity	Difference
Acidification Potential	[kg SO_2-Eq.]	1,839E-04	8,517E-04	463%
Global Warming Potential	[kg CO_2-Eq.]	1,397E-01	2,563E-01	183%
Marine Aquatic Ecotoxicity Pot.	[kg DCB-Eq.]	1,555E+00	1,631E+02	10487%
Ozone Layer Depletion Potential	[kg R11-Eq.]	1,768E-08	4,867E-09	28%
Photochem. Ozone Creation Pot.	[kg Eth.-Eq.]	4,685E-05	4,934E-05	105%

Results presented in Table 5 mean, that even the significant reduction of thermal energy consumption cannot compensate the increased electric energy demand from the point of view of “long-term” impact categories, such as Marine Aquatic Ecotoxicity Potential. Further discussion about suitability and applicability of these impact categories in building industry is out of scope of this paper.

6 CONCLUSION

As the paper shows, there are many ways to interpret results of the environmental assessment. Both conducted assessments were based on the same data. Relatively small (between 10 to 15 %) difference of the results in Global Warming Potential impact category can be regarded as confirmation of the accuracy of the assessments done by both software tools. Therefore it should be said, that both tools are suitable for the assessment of environmental impacts of building renovations under the IEA ECBCS Annex 56 project. GaBi with its possibility for use of any available database and characterization model is the tool for precise assessments. From this point of view Eco-Bat can be seen as inferior to GaBi. But the intention of its authors was to create easy-to-understand building assessment tool, not a complex (and complicated) research tool. And it is its simple interface combined with the fact that it by default evaluates both main points of interest of the Annex 56 project (energy consumption and carbon dioxide production) what should be taken into consideration when choosing tools for future assessments.

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Regenerative universities? The role of universities in urban regeneration

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ABSTRACT: Though Universities have long been special places, the emergence of the *Knowledge Economy* brought back their missions to centre stage. More than ever they are viewed as socioeconomic progress sources and are encouraged to develop innovative solutions to Urban Regeneration. This investigation addresses the role of the University in modern urban development, specifically within Urban Regeneration, both as its *dissemination agent* and as one of its *subjects*, encompassing three main sections. Firstly, it comprises a discussion of the University within the *Knowledge Economy*. Secondly, it includes an outline of the current missions of the University. Thirdly third it explores the roles of the University within Urban Regeneration. Thus, it is proposed that the University can strongly benefit and improve *urban regeneration practices* and *processes*, when assuming a starring dissemination role. As a central nodule in the *Knowledge Economy,* it can further encourage integrated-sustainably-oriented practices, extended to its surroundings.

1 INTRODUCTION

Universities have long been special places, homes to both innovation and resistance, but essentially, they are unique (M'Gonigle & Starke, 2006, p. 7,10,13): they are rooted locally, yet networked globally; connected to the past, yet shape the future; transcend intellectual, geographic, temporal, and socioeconomic boundaries; provide public spaces, though being specific places; and are at the centre of change. The *Knowledge Economy* has asserted the University's central role (Fallis, 2004, p. 21). It has become crucial to our economy, to our health care, to our culture (Fallis, 2004, p. 5), and to the revitalisation of our cities (Fernández-Esquinas & Pinto, 2013, pp. 1–19). The University is being encouraged to develop innovative solutions to restructuring cities, while simultaneously becoming both *agent* and *subject* of Urban Regeneration. This investigation addresses the role of the University in urban development, specifically its supporting role in Urban Regeneration, by acting as a conduit in the dynamics of local development.

One of the phenomenon that has accompanied the rise of the *Knowledge Economy* has definitely been the renewal and revitalisation of urban centres, especially the one started in the last decade of the twentieth century, i.e., trough Urban Regeneration (Ferreira, 2008, pp. 19–37). Urban Regeneration can be seen as a comprehensive strategy (Roberts & Sykes, 2000, p. 17) that integrates urban planning with the resolution of socioeconomic and environmental problems (Ferreira, 2008, pp. 49–53), by improving the capacity of cities to meet the standards of *Knowledge Economy*. Considering this background, the University can now have a unique position to establish a different urban relationship (Magdaniel, 2012, p. 2): (1) as an object in two distinct scales: a system of its own (a city within the city) and a part of a larger urban system; (2) and as the driving force of the *Knowledge Economy*.

The University, as a *Knowledge Pole* (KPL) is viewed, as both a crucial site for (Fernández-Esquinas & Pinto, 2013, pp. 1–19) and a potential "*generator-pole*" of Urban Regeneration (Nunes, Tomé, & Pinheiro, 2012, pp. 6–9).This investigation intends to foresee and highlight the possible role of the University as an active *subject* and *agent* of *regeneration strategies,* addressing its part in the dissemination of balanced socioeconomic and environmental patterns. This investigation comprises three main sections. Following this introduction, the first section includes the discussion of the University within the *Knowledge Economy*. The second section includes an outline of the contemporary missions of the University. The third section explores the University both as a *subject* and *agent* of Urban Regeneration. This investigation is expected to stress the potential role of the University in assisting and improving, either as a *subject* or an *agent*, the application of *regeneration strategies*, further encouraging the introduction of integrated and sustainably-oriented practices that are extended and applied to its surroundings.

2 THE UNIVERSITY WITHIN THE KNOWLEDGE ECONOMY

The relationship between Universities and Cities has a long history (Fernández-Esquinas & Pinto, 2013, p. 3) given that *knowledge* has occupied a central place in economic growth and progressive elevation of social welfare (David & Forey 2002, cited in Cardona, 2007, p. 2). The transformations experienced by both during the twentieth century have run in parallel and have been inter-related (O'Mara, 2012, cited in Fernández-Esquinas & Pinto, 2013, p. 3). Moreover, the challenges facing both Universities (M'Gonigle & Starke, 2006, p. 10) and Urban Societies in the new millennium could arguably be considered the greatest ones yet. As industrial sectors lost their significance (Ferreira, 2008, pp. 19–37), *knowledge* intensive sectors gained protagonism, paving the way for a *Knowledge economy* (global scale) or *economies* (national, regional or local scales) dominated by *services*, a *professional/technical* class and *theoretical knowledge* (Bell, 1967, pp. 24–32).

Knowledge Economies are knowledge-based economies in which the creation, distribution and use of knowledge is the principal driver of growth, wealth and employment (Heng et al., 2002 cited in Cardona, 2007, p. 6) These economies deliver growth through developing competitive advantages in *knowledge* or *technology* intensive sectors (Yigitcanlar, 2011, p. 53), stressing a greater reliance on intellectual capabilities (Powell & Snellman, 2004, p. 201) and engaging in self-conscious research programs to advance *knowledge* and solve applied problems, as never before (Fallis, 2004, p. 21). Thus, Cities now procure to succeed in the Knowledge Economy and strongly benefit from having robust *knowledge infrastructures*, dense *knowledge resources*, attractive *amenities*, a concentration of well-educated *knowledge workers*, and global *economic connections* (van Winden et al. 2010, p. 2).

The *Knowledge Economy* has increased the relevance of *location* (Evers, 2008, p. 4) by emphasising the role of existing *knowledge infrastructures*, such as Universities. As Kerr (1963, pp. xi–xii) emphasizes, "*the basic reality, for the University [in the Knowledge Economy], is the widespread recognition that new knowledge is the most important factor in economic and social growth./…knowledge, may be the most powerful … element in our [contemporary] culture, affecting the rise and fall … of regions and even… nations.*". Indeed, if the business firm was the key institution of the past one hundred years, the University will replace it for the next one hundred, due to t role as the new source of *innovation* and *knowledge* (Bell, 1967, p. 30). Moreover, the University plays a special role, as "*… the chief innovative [force] of … Society, one of the chief determinants of social opportunity and … stratification, and a focus of intellectual and cultural life*" (Fallis, 2004, p. 21).

As the *Knowledge Economy* came to the forefront, the University evolved simultaneously and the usefulness of its knowledge and products began to transcend its boundaries – "*science became a global force [and] its truths universally accessible*" – assert M'Gonigle & Starke (2006, pp. 33–34). The University has become an "*interrelated system of knowledge production so large and powerful that it can be understood as the higher education industry*", evolving as an "*economic actor in its own right*" (ibid, p. 35). The University has truly become an important institution (Fallis, 2004, p. 5). The University is not only an *industry* in the new *Knowledge Economy*, it is also the "*mother of all industries*", since it has trained the specialists of most other industries, according to M'Gonigle & Starke (2006, p. 36). The authors claim that today there is even a symbiotic relationship between global economic growth and the newly coined higher education industry (ibid, p. 38).

Higher Education is considered to be the world's top industry because of its size, its role in supplying employees, ideas and spin-off effects to other major industries and its unparalleled geographic reach (ibid, p. 38). Moreover, within the *Knowledge Economy*, the University can act as an urban catalyst, considering that it offers local employment opportunities, addresses local and regional workforce needs, can channel expertise to increase local business capacity or environment, offer services to start-up companies, promote expedite research commercialisation, while redirecting institutional purchase toward local businesses, using its real estate development to anchor local economic growth (ibid, pp. 101, 179–183) and developing into an enclave for nurturing innovation (Nunes et al., 2012, p. 9).

Within the *Knowledge Economy*, the University in its entirety, can be viewed as a *Knowledge Pole* (KPL), i.e., as a *local or regional innovation system of agglomerated organisations, that are both (1) geographically concentrated in one or several physical areas and (2) virtually concentrated as central points in wider knowledge sharing networks, whose primary role is knowledge (a) production, (b) transmission, (c) sharing, (d) mediation and (e) application*. Within this conceptual formulation, non-human constituents (physical and virtual space, material and immaterial assets and infrastructures) are further denominated as *actors* and assume similar proprieties to those advanced by the Actor–network theory (see Latour, 2005). These *actors* can be defined as *Knowledge Clusters* (KCRs), *Knowledge Hubs* (KHs) and *Knowledge Performers* (KPRs) or, through a computer science metaphor: hardware (KCRs), software (KHs) and developers or users (KPRs).

A KCR is a *geographically proximate* (M. E. Porter, 2000, p. 16), *agglomeration of organisations that are primarily production-oriented towards knowledge, as an output or input, and have the ability/capability to drive innovation and create new outputs* (Evers, 2008, p. 9). A KCR (1) enables facility sharing, enhanced networking, face-to-face contact, plus interactions between people and organisations; (2) offers a set of economic benefits, by fostering industry-organisations links and start-ups; (3) nurtures urban identity, providing local economies with a "*face*" and an "*address*" (Van Winden et al., 2010, p. 3). It is most visible as a *"[material] agglomeration of organisations and buildings*" (Evers, 2008, p. 11). The physical impersonations of Universities sub-constituent organisations and locations, as material assets and physical spaces, are the effective constituents of KCRs, i.e., the "hardware".

A KH is a *local innovation system that is a node within knowledge production and sharing networks, characterised by high connectedness and high internal and external networking and sharing capabilities* (Evers, 2008, p. 10). A KH may exist in the same locations as a KCR and may be nested within it. As a meeting point of communities of knowledge, a KH: (1) generates *knowledge*, (2) transfers *knowledge* to sites of application; and (3) transmits *knowledge* through education and training (Menkhoff & Evers, 2011, pp. 3–4). In a KH other KHs are accessed and *knowledge* is shared throughout a *Knowledge Network*; its resilience and strength rests on its degree of internal and external connectivity (Evers, 2008, p. 10). A KH is most visible as a community of knowledge sharing and producing agents (Evers, 2008, p. 11), including the immaterial infrastructure that supports it. The agents whose performance is based on knowledge are the KPRs, the last actor. They are responsible for performing the roles of producers of knowledge, operators of knowledge transmission, sharing or dissemination or are simply end-users of knowledge, either simultaneously or separately, either assuming the character of university users or organisations.

3 THE MISSIONS OF THE UNIVERSITY

As the University becomes a primary institution of the *Knowledge Society*, "*its missions [and its relationship with society] are moved to centre stage*" (Fallis, 2004, p. 21). Thus, a powerful metaphor to describe the relationship between the University and Society is that there is a "*social contract*" between them (Bok, 1982, p. 5). The modern University comes into existence to meet the needs and aspirations of democratic societies and as such these must be determined in each age, responding to the transmutating needs of the one that supports it (Fallis, 2004, p. 3,6,34). Fernández-Esquinas and Pinto (2013, p. 2) add that to understand the contemporary potential of the University, it is necessary to consider its heterogeneous missions and observe their implications for specific territorial sites.

The University, in its social contract with Society, has been assigned certain tasks, serving many purposes and has been granted autonomy in pursuing them (Fallis, 2004, pp. 32, 38): (1) it provides mass undergraduate and graduate education and opportunity for social mobility; (2) it is the centre of Society's organized research enterprise; (3) it provides liberal education for citizenship and trains the future, self-regulated professionals; (4) it is both the means to pass on a shared culture and the means to re-define this culture. The "*social contract*" implies an obligation to reflect upon these tasks and discuss them publicly, to articulate their value in Society, to defend them when threatened, as well as to reconsider them in light of criticism and transmutating needs (ibid, p. 38). As the "*social contract*" is renewed, it is important to specify the University's missions.

Many authors have agreed on three fundamental missions: *education* (1), *research* (2) and *social endowment* (3), as Fernández-Esquinas and Pinto (2013, pp. 2–7) and Fallis (2004, pp.

13–32) explain. Others, such as Goddard (2009, pp. 9–14), argue that a "fourth mission" is emerging - the *economic mission*. Within the *Knowledge Economy*, this line of argument is further stressed (M'Gonigle & Starke, 2006, pp. 33–36). Nevertheless some of these missions and sub-missions become entangled and hard to distinguish. Likewise, Universities do not always pursue them simultaneously or with the same commitment, adds Fallis (2004, p. 14).

The first, original and most long-lasting mission of the University is (1) *education* (Fallis, 2004, pp. 16, 24–25; Fernández-Esquinas & Pinto, 2013, p. 1; Gilderbloom & Mullins Jr., 2005, pp. 1–16; Goddard, 2009, pp. 2–5; Magdaniel, 2012, p. 2). It includes: (1a) *liberal undergraduate education*, which is theoretical in orientation; (1b) *graduate education*, which is an exclusive feature of universities and becomes more specialized; (1c) *professional education*, whose curricula covers a specialised body of knowledge, recognizing the importance of apprenticeship and practical experience; lastly (1d) *the responsibility to be accessible to all*, who are capable of and willing to undertake university study. The second is the scientific (2) *research mission* (Fallis, 2004, pp. 17–19; Fernández-Esquinas & Pinto, 2013, p. 1; Gilderbloom & Mullins Jr., 2005, pp. 1–16; Goddard, 2009, pp. 2–5; Magdaniel, 2012, pp. 5–6), which also becomes a distinguishing characteristic of the University, as its professionals become up-to-date and active scholars in the areas where they perform; it connects the University to Society in a fundamentally new way, as new knowledge is useful and therefore financially supported. This mission includes the following sub-missions: (2a) *new knowledge production and innovation*; (2b) *knowledge dissemination and spillovers*; and (2c) *practical knowledge application*.

The third mission is the (3) *social mission* (Fallis, 2004, pp. 46–47; Fernández-Esquinas & Pinto, 2013, pp. 4–5; Gilderbloom & Mullins Jr., 2005, pp. 1–16; Goddard, 2009, pp. 7–10; Magdaniel, 2012, pp. 6–7), which pays greater recognition to universities doing more to engage socioeconomic and environmental problems and includes: (3a) the *facilitator role*, i.e., as an integrate and unbiased, process and project mediator; (3b) the *equity partner role*, i.e., as an investor in a specific partnership; (3c) the *technical resource role*, which comprises (3c1) *providing continuous education*, (3c2) *knowledge transfer & research application*, (3c3) *business incubation* and (3c4) *other services* (e.g. *consulting*, *project design & development*); lastly (3d) the *critic role*, which should be guarded vigilantly, as critical ideas and alternatives must be advanced according to the scholarly canons. The last mission is the (4) *economic mission* (Fallis, 2004, p. 22; Fernández-Esquinas & Pinto, 2013, pp. 3–4; Gilderbloom & Mullins Jr., 2005, pp. 1–16; Goddard, 2009, pp. 9–14; Magdaniel, 2012, p. 4), which comprises an "entrepreneurial" perspective, and is not always recognised as such. As an actor capable of diluting distances between various nodes of innovation systems, the University can promote the (4a) *commercialization of research*, (4b) the *creation of new firms through knowledge spill-overs and incubation*, (4c) the delivery of *other paid services* and the (4c) *generation of gains through equity partnerships*.

4 THE UNIVERSITY AND URBAN REGENERATION

As a result of assertions that knowledge-intensive industries are now at the core of growth, in the new *Knowledge Economy* (M'Gonigle & Starke, 2006, pp. 101, 179–183), urban landscapes have been subjected to a "*widespread and comprehensive re-imagination of city centres*" (Tallon, 2009, pp. 20–21). Thus, many European cities have changed, as their economic bases were restructured (Teixeira, 2010, p. 98). The contemporary desire of governments for the "*renaissance*" of their cities has become a defining feature of contemporary policy (L. Porter & Shaw, 2009, p. 1). The benefits of reinvesting in urban spaces made redundant by years of neglect are clear, but there are also good arguments for "*regenerating*" areas that, while still vital, have experienced sustained disinvestment.

Cities that procure to succeed in the *Knowledge Economy* benefit strongly from pursuing and developing robust *knowledge infrastructures*, dense *knowledge resources* and attractive *amenities*, in order to further attract *knowledge workers* (van Winden et al. 2010, p. 2). Thus, the Urban Regeneration (Ferreira, 2008, pp. 19–28; Roberts & Sykes, 2000, pp. 10–36):10-36) of city centres has been one of the phenomena that has accompanied the rise of the "*Knowledge Economy*", as a response to the changing urban patterns of competitive advantage. Moreover, an *integrated regeneration* can further contribute to the potential resolution of problems such as the current socioeconomic situation, climate change, resource consumption and/or urban decline (Teixeira, 2010, p. 97).

In addition to encouraging cities to compete externally, governments have realised the importance of cities as centres of innovation and enterprise within regional (Jones & Evans, 2008, p. 57) and national economies. Within this context, higher education institutions as Universities and Research Centres act as both centres for knowledge production and catalysts for innovation (Jones & Evans, 2008, p. 56). The University as the "*primary institution of the Knowledge Society*" (Fallis, 2004, p. 21), can become an ideal potential *subject* and *agent* to promote a *comprehensive* and *balanced regeneration* of urban environments, as attested by Fernández-Esquinas and Pinto (Fernández-Esquinas & Pinto, 2013) and (Nunes et al., 2012, pp. 6–9).

In line with this, new realignments of urban policies can be observed in relation to the role of the University (Fernández-Esquinas & Pinto, 2013). These acknowledge that in addition to physical planning and land use, more holistic approaches take educational, cultural and social aspects into account as essential resources for urban development processes; other relevant approaches integrate the University as a key player in local innovation systems or in the emergence of *creative* or *knowledge environments*; these approaches observe how universities foster *human capital* and help connect the local context with technological developments with a global impact.

Through reflecting on the University Campus in an urban milieu, Magdaniel (2012, pp. 4–8) identifies five main roles played by the University in cities. Firstly, the role of *actor for urban economic growth* (1) - *education* and *R&D* become important functions in the city that generate and/or support economic urban growth. Secondly, the role of *engine to attract, shape and retain knowledge workers* (2), whose value is crucial for regional *Knowledge Economie*s. Thirdly, she points out the role of *node in a collaborative network* (3) that comprises cross-sector local and regional and/or inter-institutional collaboration. The author also stresses the University as a *city within the city* (4), which addresses the relationship between the University and the city as a symbiotic relationship. Magdaniel (2012, pp. 4–8) discusses the University's final role of either or of both a *real estate developer* (5a) and an *agent of urban changes* (5b).

The urban roles mentioned by Magdaniel (2012, pp. 4–8) are intrinsically related with the missions of the University, identified in section 3: the *educational*, *research*, *social* and *economic* missions. Lastly, given that the University is a major piece of urban infrastructure, its implications are obviously simple because it is a visible organization with an important socioeconomic role within urban dynamics, i.e., it has an urban effect by its mere existence (Fernández-Esquinas & Pinto, 2013). In this context, other authors have further stressed, within the underlying conjunction of these roles, that the University can potential become both a *subject* and an *agent* for Urban Regeneration (Nunes et al., 2012), within the context of the *Knowledge Economy*.

Taking this into consideration, as well as Fernández-Esquinas & Pinto (Fernández-Esquinas & Pinto, 2013) approach of identifying the effects of the University in *regeneration processes*, *a summary of potential explicit and implicit outcomes of UR processes that either target the University as a subject or as an agent for UR* has been compiled. This investigation considered Fernández-Esquinas & Pinto's (Fernández-Esquinas & Pinto, 2013) four effect dimensions, adding a fifth, "*environmental sustainability*" while simultaneously compiling two of them, "*civic engagement*" and "*human resources*" under a new dimension, "*social development*".

The approach taken in this investigation identified the *explicit* and *implicit outcomes* of a *knowledge-based* Urban Regeneration, according to four main dimensions and two secondary sub-dimensions: (1) "*physical infrastructure*"; (2) "*social development*", (2a) encompassing "*civic engagement*" and (2b) "*human resources*"; "*economic development*" (3); and "*environmental sustainability*". Each dimension or sub-dimension was further divided into two, according to the outcome being originated from *knowledge-based UR processes* that tackle the University either as a *subject* (the KPL is submitted to a *regeneration intervention*, that includes all *university actors*: KCRs, KHs, and KPRs) or as an *agent* (the KPL, becomes an equity partner, a stakeholder and/or an active agent in disseminating, introducing and applying *regeneration strategies* in its surroundings and contiguous community - all *university actors* become involved in this regeneration process).

Additionally, each of the above subdivisions was further subdivided into two groups, separating the outcomes that tend to form an *explicit part* (+) from those that form an *implicit part* (*) of *regeneration strategies*. According to Fernández-Esquinas and Pinto (Fernández-Esquinas & Pinto, 2013), who originally introduced this division, it facilitates the understanding of both the more proactive uses of universities in strategic planning processes (+) and non-specifically planned effects (*), further considering that a given outcome can (+) or cannot (*) be fulfilled in the contextual scale-settings in which it is promoted. The following table (1) summarises potential explicit and implicit outcomes of *regeneration processes* that either target the University as a *subject* or as an *agent*.

Table 1. Outcomes of the University as a *subject* and *agent* of Urban Regeneration: explicit and implicit effects

	University as a *subject* of UR	University as an *agent* of UR
Physical infrastructure	The University as an urban amenity	The University as an agent of urban planning
	Property regeneration and expansion (+)	Property Development – housing, services, etc. (+)
	Reclassification of land uses for buildings, green and/or public spaces and other uses (+)	Territorial valorisation and optimisation, occupation of urban voids and regeneration of existing land uses (+)
	Provision of "*knowledge infrastructures*", as "knowledge spaces" and locations for business-incubating (+)	Development of "*knowledge infrastructures*", "knowledge spaces", locations for business-incubating and science or technology parks (*)
	Provision of cultural, sport and green spaces (*)	Development of cultural sport and green spaces (*)
	Promotion of landscape integration and built / natural heritage protection and enhancement within the university premises (*)	Landscape integration and built / natural heritage protection and enhancement of surrounding and local urban environments (+)
Social Development – Human Resources	Education, training and specialisation	Population dynamics
	Production of under/graduates for strategic sectors (+)	Increase of the educated workforce (*)
	Influx of university-educated population (+)	Demographic change (*)
	Circulation of knowledge workers (+)	Social and spatial mobility (*)
	Specialized training for local workers (*)	Requalification of the work-force of strategic sectors (+)
Social Development – Civic Engagement	Social commitment	Social and Cultural Capital
	Promotion of R&D focused on local needs (+) Knowledge dissemination and spillovers (+)	Applied research and consulting focused on local needs (+)
	Increased involvement of the university population in local and community issues (+)	Enhancement of the involvement capacity of the local population in local community issues (*) Increased public participation (*)
	Involvement in solving social problems: education, poverty, health, inclusiveness, etc. (*)	Mediation and promotion of social problem solving: education, poverty, health, inclusiveness, etc. (+)
	Promotion of collaborative networks (+)	Promotion of denser social networks (+)
	Promotion of local identity, liveability and cohesion (*)	Strengthen the sense of place and community (+)
	Development of security and safety strategies (*)	Application of security and safety strategies (*)
Economic Development	The University as an economic agent	Economic regeneration
	Promotion of partnerships with local stakeholders (*)	Local investment – the University as an equity partner (+)
	Employment generation - University as local employer (+)	Revitalization of local suppliers - University as customer of local businesses (*)
	Commercialization of scientific research – University as a generator of local income (+)	Promotion of different and optimised sources of local income (+)
	Knowledge transfer and business incubation (*)	Creation of new businesses to meet University demands (*)
	Provision of specialised services (+)	Attraction of specialised businesses (+)
Environmental Sustainability	Commitment to sustainability	Environmental regeneration
	Development of bioclimatic design solutions (*)	Promotion of bioclimatic architecture (*)
	Development and implementation of energy and water efficiency techniques and targets (+)	Promoting local energy and water efficiency and establish local efficiency targets (+)
	Development and promotion of on-site energy production from renewable sources (+)	Development of local energy production and promoting the adoption of renewable energy sources (+)
	Reduction of the University's carbon footprint and development / promotion of environmentally-friendly travelling and increase local accessibility to all (*)	Reduction of local carbon footprint and promotion / adoption of environmentally-friendly transport systems and increase local accessibility to all (*)
	Reduction of waste and wastewater loads, and development of on-site valorisation of both (*)	Promoting local waste and wastewater reduction, treatment and valorisation (+)
	Promotion of air/noise emissions, thermal/light pollution reduction and development of control strategies (*)	Promotion of air/noise emissions and thermal/light pollution reduction and establishment of control targets (*)
	Development and application of environmental information and management techniques and systems (+)	Dissemination and application of environmental information and management techniques and systems (+)

Based on the original work of Fernández-Esquinas and Pinto (Fernández-Esquinas & Pinto, 2013).

The University, as a *knowledge location* (Evers, 2008, pp. 9–10) and thus a KPL, can potentially be develop into a seedbed or enclave for nurturing the rise of new entities that locally stimulate production and innovation, catalyse growth, and ultimately promote Urban Regeneration (Nunes et al., 2012, p. 9). KPLs can influence a *knowledge-based regeneration*, as they can contribute with financial resources and eventually act as anchor tenants, influencing the *regeneration concept* and *vision* (van Winden et al., 2010, p. 177), as well as being themselves influenced by such vision. As a KPL, the University can additionally become the catalyst that attaches sustainability to the *regeneration processes* and produces *innovative business environments* (Marques & Leite, 2004, p. 69), as well as sustainable urban environments.

KPL's main actors can also contribute to Urban Regeneration. On the one hand, KCRs can hypothetically leverage *regeneration processes*, simultaneously performing as key elements in the generation of new functions of urban space, as their vocation is directed to productive activities (Marques & Leite, 2005, p. 15) and more specifically towards knowledge production. As KCRs, *University Campuses* can help foster the identity of a city as a progressive *knowledge-based city*, giving local economies a "*face*" and an "*address*", offer the ability to become prime sites of urban experimentation (van Winden et al., 2010, p. 190), e.g., as laboratories of "*green experimentation*" and "*user-driven innovators*", contributing to environmentally bolster the *regeneration concept* or *process*.

On the other hand, KHs can improve knowledge transmission and communication allowing for both local and global connectivity, which can further sustain access to experts and successful experiences elsewhere, as well as they can foster the establishment of new partnerships with different stakeholders. As KHs, *University Communities* can (1) provide opportunities for facility sharing, (2) enhance networking and face-to-face interaction, (3) promote unexpected interaction between academia, companies and local communities, with positive impacts on innovation (van Winden et al., 2010, p. 3) and (4) bolster the social component of Urban Regeneration.

5 CONCLUSION

Nowadays, the University has become a central institution in the *Knowledge Economy*. It has developed into a powerful source of socioeconomic progress for the territorial contexts in which it is located. The University now has a unique position to establish a different relationship with the *regeneration* of surrounding urban environments, both as (1) a *subject* and (2) an *agent* of *comprehensive regeneration strategies*. In the *Knowledge Economy*, the University can be viewed as a KPL, i.e., a *local/ regional innovation system of agglomerated organisations, that are geographically and virtually concentrated and whose primary role is knowledge-related activities.* As a *KPL*, the University has three main actors: KCRs – the "*hardware*"*;* KHs - the "*software*"; and KPRs – the "*users*".

A powerful metaphor to describe the relationship between the University and Society is that there is a "*social contract*" between them. In this "*social contract"* the University, has been assigned certain tasks and has been granted the autonomy to pursue them. In this context, "*four-university-missions*" arise: *educational*, *research*, *social* and *economic* missions. Furthermore, the University is increasingly expected to play functions that go beyond its traditional missions of *education* and *research*, such as stimulating the dynamics of regional and urban development, potentially becoming a crucial element of Urban Regeneration.

The proposed multidimensional *summary of outcomes* of *regeneration strategies* has highlighted the potential of the University, as a KPL, to become an impending *subject* but also emerge as an *agent* of Urban Regeneration. The KPL can act on its surroundings, where the regeneration practices are more consistent and well disseminated. The summary underlines the multiple uses of the University and identifies potential responses and outcomes of knowledge-based *regeneration strategies*. Through unfolding the potential benefits of one dimension, it becomes clear that it is convenient to activate further dimensions (Fernández-Esquinas & Pinto, 2013, p. 17), as there is an interrelation between them. Nonetheless, the comprehensive entanglement of all dimensions can sustain the development of a wide-ranging, cross-scale (*University*, *neighbourhood*, *city*) and cross-object (University as *subject* and *agent*) strategy to *knowledge-based regeneration*.

All *university actors*, KCRs, KHs and KPRs can become powerful allies *within regeneration processes* and the support they provide can potentially comprise the catalyst that stresses sustainability within these processes. Thus, the University can further encourage the introduction of integrated and sustainably-oriented practices that are extended and applied to local surroundings. Lastly, the University roles of *subject* and *agent* should be pursued in unison as the beneficial effects become potentially greater. Regenerating both the "mind" (University) and the "body" (surrounding environments) will allow the attainment of a fully "healthy urban being".

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The integration of sustainable solutions in Portuguese old building architecture

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ABSTRACT: The low energy renovation of historical buildings is always a challenge for professionals. The recast EPBD allows the member states not to apply great part of its requirements to these kind of buildings and this has been not considered fundamental in building energy-renovation policies. This research aims to make an overview of possible sustainable and low energy solutions for these buildings as well as intend to focus on how deep these solutions has been implemented so far on Portuguese building renovation projects. Seven case studies, supported by the analysis of seven renovation design projects, were conducted, complemented by in-deep expert interviews. This study shed more light to the fact that it is possible to integrate these solutions and also that it is not common to adopt them in old building renovations. This study make obvious that there is an increasing awareness of professionals involved about the importance of this issue.

1 INTRODUCTION

There is a growing recognition of the architectural and cultural value of buildings in historic city centers. Gradually governments recognize the contribution that built cultural heritage makes to the social well-being of different groups living in villages and cities (Tweed & Sutherland 2007). However, there are a great number of abandoned old buildings in many city centers. Portugal, unfortunately, has many of these examples. The historic city centers problems and the barriers to its renovation are thoroughly known. The visible level of deterioration, the decrease of building indoor habitability conditions and the real estate speculation are examples. Portuguese social and urban planning policies and regulations have been over the years less focused on the increase of the building renovation but more directed to new buildings. So far, governments did not offer the sufficient policy tools to encourage the maintenance of privately owned historic buildings. Nevertheless, there are some signs of a growing interest on historic centers by some specific social groups, as for example, university students and young couples. According to Queirós (2009) the historic city centers provide uncountable benefits and opportunities, since they can be enjoyable living places in an historic and cultural environment, have a strong potential for tourism activities, can be attractive both commercial and services areas and can offer local employment opportunities, thus helping local economy. Teller & Bond (2002) considers that is crucial to found new socio-economic uses for heritage buildings areas, in order to maintain them in sustainable activity cycles.

On the other hand, sustainable buildings became nowadays the key to addressing multiple challenges despite much of the focus so far has been mainly on energy efficient issues. Meijer et al. (2009) considers that existing building stock will continue to dominate for the next years and its sustainable renovation is needed mainly for its energy-saving potential. But in an holistic point of view, the renovation of old buildings should embrace energy efficiency, low carbon emissions, harmonized relationship with the surrounding environment, cost effectiveness, economic viability, and social equity and cultural identity (Yung & Chan, 2012).

2 SCOPE AND METHODOLOGY

The focus of this paper, as a part of a wide research titled “Renovation management in urban historic centers", is to give an evidence-based image of how deeply the subjects related with sustainability, energy efficiency and bioclimatic solutions are been implemented in the Portuguese old building renovation design projects. At the same time, possible sustainable and low energy solutions are proposed.

In order to reach the aim of this study, a literature review on scientific literature, political documents, national and international reports and data bases was held. Following, this research was divided in two different phases and two different data sources, in order to ensure well-founded and reliable data. An analysis of seven case studies was the first step. Seven different building renovation design projects, were reviewed and object of a comparative analysis. Only one of the seven design projects was near to be complete and there was missing data in most of them due to the fact that not all parts/specialties of the design project were available. Due to the lack of information on the design projects and for achieve more accurate data, expert interviews to a group of selected stakeholders were held. The interviews involved Portuguese architects and civil engineers. The interviewers work mainly in design project activities, construction management and supervision of old building renovation. The possible answers to the questions were “YES” or “NO” and additionally they could write some comments. It was only possible to make fifteen interviews in a group of forty potential stakeholders because twenty five did not reply.

3 MAIN CHARACTERISTICS OF BUILDING STOCK AND RENOVATION CONCEPTS

3.1 *Historical and old building stock data*

European statistics reveals that 14% of European building-stock dates before 1919 and 12% between 1919 and 1945 (Euroconstruct 2013). According to the most recent available data from INE (2013), Portugal has 5 878 756 accommodations in a total of 3 518 152 buildings. Old buildings, built before the year 1945, represent 14,4% of the Portuguese building stock. The Table 1 represents a relation between these type of buildings and their repair needs.

Table 1. Relation between buildings age and repair needs

Construction time (age)	Before 1919		Between 1919 and 1945	
Buildings numbers and percentages	N.º	%	N.º	%
Without repair needs	77.326	2,18	125.924	3,55
With repair needs	106.616	3,01	162.017	4,57
Very degraded	22.381	0,63	17.755	0,5
Total	206.343	5,82	305.696	8,62

It is estimated that 10,6% of Portuguese existing building stock built before 1945 does not have concrete structure. From a total of 305 696 old buildings built between 1919 and 1945, 135 596 have concrete structure and masonry walls with concrete slabs. There are 268 633 old buildings (7,58%) built before 1945 with repair needs and there are 40 136 buildings (1,13%) with a high level of degradation. In total there are 308 769 old buildings with renovation needs, which is 8,71% of total Portuguese existing building stock. On energy use matters, Meijer et al. (2009) found that in most buildings statistics it is usually to found no data available.

3.2 *Sustainability and energy efficiency as recommendations for building renovation*

According to the ISO 13822:2010 (2010), the sustainable construction principles are applied when existing materials and structures can be reutilized, instead of replaced by new ones, following building life cycle principles. The sustainability and energy efficiency issues are included in the agenda of many European governments and therefore it is nowadays common to found these issues as a part of many regulations, policy documents and several associations documents and reports.

According to Plessis (2002) the sustainable practices could be more expressive using the following construction sustainable principles, published in the First World Conference About Sustainable Construction (Kibert 1994), such as: minimize resources consumption; maximize resources reutilization; use renewable and recycled resources; protect natural environment; create health and not toxic environment and develop quality comfort in the built environment.

Addressing the latest Portuguese Law 32 (2012) that regulates Portuguese urban and planning renovation activities it is evidence-based the concern about sustainability. This legal framework refers that is important to: promote buildings energy efficiency; improve habitability, functionality and comfort indoor conditions; bring up to date infrastructures and regenerate city gardens; develop conditions to walk and increment the bicycle transport use; protect cultural historic and heritage as identity and culture value and promote the environmental, social and economic sustainability in urban areas.

The ICOMOS (International Council on Monuments and Sites) (2003) also propose technical recommendations and guidelines to adopt particularly in old buildings and heritage protected areas. The most relevant are: make preliminary studies of the building conservation level; reduce the intervention impact to maximum and focus on the replacement of deteriorated parts; identify the problems and define potential solutions; make the compatibility between new and existing materials; promote the reversibility and maintain the original constructive techniques; improve the energy performance and comfort levels; develop water reduce consumptions and energy efficiency solutions; respect the building life cycle and promote maintenance and conservation policies; preserve elements with recognized cultural and historic interest; prefer deconstruction techniques in case of demolition and identify the problems and constraints to reduce risks and unexpected situations.

3.3 *An overview of sustainability strategies on building conservation and renovation*

Renovating an old and historical building is a demanding challenge for professionals. Fielden (2003) refers seven different levels of action in an old building: deterioration prevention, preservation, consolidation, restoration, rehabilitation, reproduction and reconstruction. According to Paiva (2006) the renovation can comprise simple tasks as paintings, small repairs, modification of indoor space functions and demolition of some simple building parts or be more complex, such as, reconstruction or restoration. A well-done preliminary diagnosis is a crucial support instrument for the correct decision. The ICOMOS (2003) define historical buildings renovation as the "*process to bring a building to a new use or function, without change the portions of the building that are significant to its historical value*". These practice represents an opportunity to make possible a contemporary use of the buildings. This activity require specific and multidisciplinary knowledge, which success depends on a coordinated and efficient management effort between conservation, technical and urban development professionals and experts. Today, some authors use the term adaptive reuse of buildings. "*It is a form of sustainable urban regeneration, as it extends the building's life and avoids demolition waste, encourages reuses of the embodied energy and also provides significant social and economic benefits*". (Yung & Chan, 2012). Adaptive reuse of historic buildings has increasingly emerged in urban conservation, in particular in the developing countries however it is more difficult than the reuse of ordinary buildings because need to have minimal impact on the building heritage value. Santoli (2003) refers that building maintenance and restoration are an important contribution to sustainability. This author is from the opinion that "*the production and the use of energy using high efficiency strategies, when appropriately developed, may represent an important tool for the protection and conservation of the cultural heritage*". He also believes that this attitude makes possible the successful integration of technological solutions and the improvement of the conservation conditions, considering energy efficiency as the proper tool to be used in the conservation of cultural heritage. Nevertheless, there are heritage consultants that point out that conservation principles are the prime concern and that environmental performance criteria is not the most important consideration in the renovation of built heritage (Yung & Chan 2012).

Nonetheless, the recast Energy Performance Building Directive allows the member states not to apply the requirements to buildings and monuments officially protected or having an architectural or historic value or even being part of a particular environment if this could alter their identity and appearance. In result of that, the predisposition of the stakeholders involved is normally not to apply low energy solutions to this group of buildings because they not feel it is mandatory. One important thing to underline is that many old buildings use vernacular architecture. This means that they make use of one or another passive principles adapted to the local climate but this is usually not enough to get more close to the energy efficiency levels of new buildings.

After this considerations, the question is: it is reasonable to invest in the energy renovation of historic buildings? Troi (2011) considers that finding conservation-compatible solutions for the energy renovations of historic buildings enhances long-term-conservation and sustainable management of these buildings and urban centers. This author estimated that old buildings energy renovation in the EU-27 can save 180 Mt CO2 within 2050. Although it is a major challenge to renovate energy-inefficient old buildings to lower energy consumption attending its very specific demands it offers better thermal comfort and increase property value. There are some European countries were this started to be a current practice some years ago and where some ongoing projects, that include experts, industry partners and stakeholder associations, are developing passive and active energy-renovation solutions for historic and old buildings (Troi & Lollini 2011).

3.4 *Barriers to building renovation*

As in renovation in general, the specific market of conservation and renovation of old buildings faces particular barriers. The complex renovation of these buildings have, until today, contributed to the building of a barrier between professionals active in the field (Santoli, 2003).

For Portugal, Coias (2007) identified the following barriers: heritage protection is not sufficiently recognized by the governments and institutional bodies as an identity of the country culture; there are reduced knowledge and practices of conservation and maintenance; there is lack of tailored laws and policies, mainly for financing these activities; there are insufficient competencies of project designers; there is a widespread idea that new construction is easier then renovation and that gives a better cost-benefit relation; many situations observed demonstrate a lack of qualified professionals to implement sustainable solutions and lack of adequate know-how on traditional construction techniques and finally there are not sufficient R&D on this field.

At an European level, studies (Meijer 2009, BPIE 2011) confirm as barriers the lack of knowledge and experience, the not convincing cost-benefit relation for the investor, the inappropriate products that are geared mostly towards new construction and few best-practice examples.

4 THE INTEGRATIONS OF SUSTAINABLE SOLUTIONS IN OLD BUILDINGS

4.1 *Sustainable and energy- renovation building solutions*

It is recognized that the construction technologies for renovation are relatively new and, unfortunately, most R&D and products development is directed toward new construction. The growing tendency of the building renovation market probably will stimulate, in a near future, the development of new products, that can also be used in historic buildings. According to Kibert (2005) there are some sustainable solutions that are possible to apply (Tables 2 and 3).

Table 2. Possible building sustainable solutions for renovation

Solutions	Description
Passive heating systems	- It is possible to apply individual or collective passive solar technologies however there are some existing elements that acts as barriers (Table 3).
Passive cooling systems	- Possibility to implement air admission vents and air remove vents in windows and roofs (at a higher level and in the opposite side).
Lighting	- An effective architectural study must be done to find the best solutions for natural daylight using existent windows, open spaces, light colors, light tunnels and others. Adoption of more efficient artificial lighting systems: LED, automatic switches, temporized lamps is also a strategy.
Construction Materials	- Some elements must be preserved and deteriorated ones must be replaced by similar ones. The new materials should: promote reversibility; deconstruction; contain recycled composition and other environmental standards during life cycle (low water and energy consumption and reduced CO_2 emissions levels in the manufacturing, transport, maintenance and recycling) and be produced near from the local of application.
Constructive technologies	- The existing building technologies must be preserved and protected. This action can promote: reduction of materials and construction resources; reduced amount of construction and demolition waste; budget savings and more building authenticity preservation.

Table 3. Possible building sustainable solutions for renovation

Solutions	Description
Land use	- Building renovation happens in urban consolidated areas and uses local infrastructures and therefore helps to preserve virgin soils.
Water consumption	- It is important to reuse water (rain water and gray water) to use on gardens and to flush toilet waste. Reduce the pressure levels, re-arrange the piping system and install other efficient equipments (water reduction taps, automatic and thermostatic taps) are also good strategies.
Energy	- The energy efficiency can be achieved by applying: photovoltaic panels on roofs (which, if possible, should not be visible from the street); an energy certification process to promote the compatibility between existing and new solutions with the preservation of cultural and historical elements and solar collectors for DWH.
Monitoring and maintenance	- The energy and water consumptions should be monitored with appropriate systems following a maintenance plan.
User's guide	- There should be a building user's guide.
Sustainable certification	- Sustainable certification can be done by assessing other sustainable methods (Leed, Breeam, SbTool, LiderA, etc) were the sustainability levels depend on the sustainable solutions adopted.

With the propose of reaching similar energy performance requirements as those established for new buildings, it is possible to adopt in old buildings a range of passive and active energy-renovation-solutions. The implementation of the solutions mentioned above in old buildings needs interdisciplinary cooperation and supplementary effort because normally standard solutions cannot be used. Constraints and building architectural character must be studied carefully and the option for reversible solutions are a kind of important practice that helps to preserve building identity.

The Tables 4 and 5 disclose passive solar solutions according to Steven Winter Associates (1997) which have applicability and are compatible with old buildings architecture.

Table 4. Solar passive solutions compatible with old buildings architecture

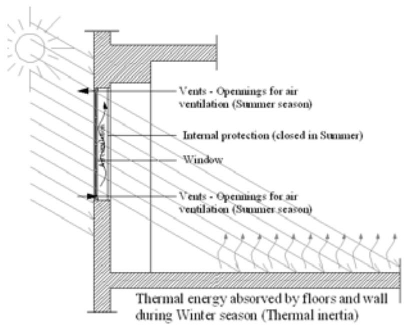
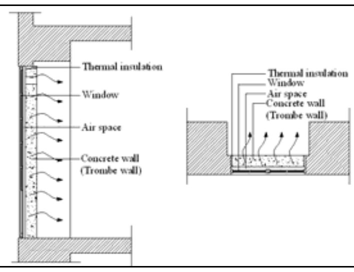
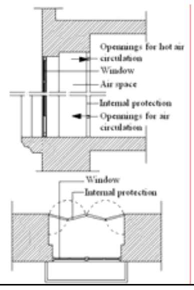
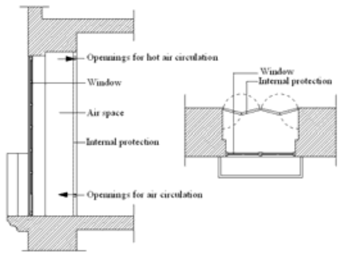
System	Descriptions	Figure
Direct gains	- Possible to apply but it has some constraints (orientation, dimensions, shading and others). - Solar radiation go directly through glass and heats the building internal elements (floors and walls). - In winter the movable insulation is open during the day to allow heating store in floors and walls and closed at night. - With south orientation it is advisable to cover windows and doors during summer with shading devices or movable insulation, which sometimes is difficult to compatible with the preservation of existing building solutions. - In summer is possible to use internal movable insulation, ensuring air circulation between this device and the window.	
Thermal storage wall (Trombe wall)	- During winter is possible to collect and store heat during the day to be transferred gradually to the indoor space, heating the room. - South orientation behind a window or a door is the best practice. Protection with solar shading systems or another insulation is important. - The integration is possible in existing windows or doors that are not usually opened, preserving existing materials and outside appearance.	

Table 5. Solar passive solutions compatible with old buildings architecture

System	Descriptions	Figures
Attached sunspace	- Good solution for the storage, distribution and control of thermal energy during the heating season. - There are some examples in vernacular architecture and it is possible to adapt contemporaneous solutions to old buildings: sunspaces, bow windows and others.	 
Convective loop	- The thermosyphon effect transfers the heated air in the channel again to the indoor space by an upper opening. - During the night is necessary to insulate the windows and close the openings. - Easier solution for applying in existing windows which preserve their original function and appearance by the outside.	

5 THE SUSTAINABILITY IMPLEMENTATION IN THE PORTUGUESE OLD BUILDING RENOVATION DESIGN PROJECTS

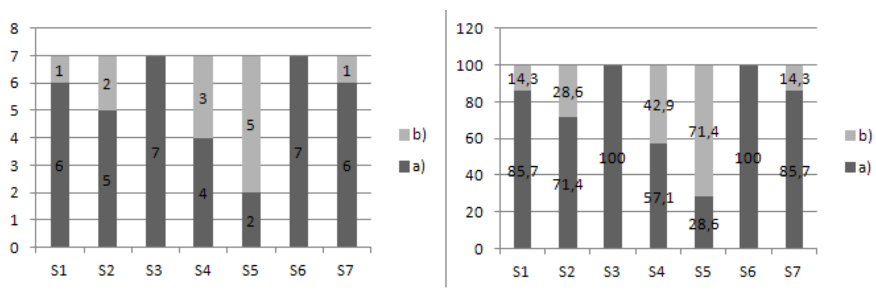
5.1 *Building renovation design projects analysis*

Seven different topics were selected for the analysis of the renovation design projects (Table 6).

Table 6. Topics - Design Project Analysis - Sustainable solutions implementation

Index	N.	Topics	
Sustainable solutions implementation	S1	Water reuse	- Water reuse systems
	S2	Solar collectors Domestic Hot Water	- Solar collector systems for DHW
	S3	Electrical energy production	- Microgeneration: photovoltaic panels and wind turbines
	S4	Energy efficiency - Thermal performance	- Thermal regulations requirements
	S5	Energy efficiency - Complementary solutions	- Natural daylight, ventilators, LED lamps, heating systems with biomass, natural gas, geothermal
	S6	Bioclimatic solutions	- Trombe walls, solariums/sunspaces
	S7	Other sustainable solutions	- Natural ventilation, green roofs, vegetation barriers for wind protection

A resume of the results of the design projects analysis is presented in Figure 1.



- a) – Design project without any reference to sustainable solutions;
- b) – Design project with references to sustainable solutions;

Figure 1: Results of the renovation design projects analysis - sustainable solutions implementation

The building renovation design projects reviewed have not any reference to "Electrical energy production" and "Bioclimatic solutions". Building solutions associated with "Water reuse" and “Other sustainable solutions” appears in only one design project. Five of the seven projects design did not use “Solar collectors DWH”. The requirements on the “Energy efficiency - Thermal performance” were considered in three of the total seven design projects. By the other side, solutions related with “Energy efficiency – Complementary solutions”, more in line with equipments and mechanical systems, were used in five design projects. One question can be made. Why there is a great number of design projects without any type of implementation of sustainable, bioclimatic and energy efficient solutions? Firstly, the sustainability issue is a relatively new concern. Secondly, one of the design projects is from 2001, two of them from the year 2011 and the remaining four from 2007 thus only two of the projects are relatively recent and even in the most recent design projects the reduced allusion to sustainable solutions was registered.

5.2 *In-deep interviews to stakeholders*

Due to the lack of some important information for research after the design projects analysis and for achieve more accurate data, it were made expert interviews to a group of selected stakeholders (Table 7). The interview´s main focus was in three of the topics.

The core questions, the results and the more relevant conclusions are in Table 8.

Table 7. Topics - Expert interviews

N.	Topics	Data source
S1	Water reuse	Interview – Question 1
S2	Solar collectors DWH	Thermal design project
S3	Electric energy production	Electrical design project
S4	Energetic efficiency - Thermal performance	Thermal design project
S5	Energetic efficiency – Complementary solutions	Electrical design project
S6	Bioclimatic solutions	Interview – Questions 2 and 3
S7	Other sustainable solutions	Interview – Questions 2 and 3

Table 8. Interviews: Questions, results and conclusions

N.	Question	Results and conclusions
Q1	- Do you consider advantageous to implement water reuse solutions on design project, like automatic and thermostatic taps and rain water and/or gray water reuse?	- Answers: 93,3% YES and 6,7% NO. - There is no doubt about the interest to implement water reuse solutions which contributes to a more sustainable environmental approach for the buildings.
Q2 and Q3	- Do you consider difficult to implement in historic centers buildings bioclimatic solutions and other sustainable solutions different than conventional ones? - Do you think is important in building renovation to considerer sustainable and bioclimatic design solutions?	- Answers to Q2: 53,3% YES, 40% NO and 6,7% without any answer. Answers to Q3: 100% YES. - The majority of the interviewed consider the fact that being historic buildings represents a constraint to implement bioclimatic solutions (Question 2). - By the other side, all stakeholders consider unquestionable to apply these solutions in building renovation design projects (Question 3).

6 CONCLUSIONS

The renovation of the historic centers and its buildings could be the opportunity to apply sustainable practices. Old buildings need conservation, indoor comfort and better energy performance to reach the functionalities required by the modern societies way of living. The studies made so far consider that historic architecture can often be adapted to meet modern requirements without losing heritage value and also that is one of the important strategies to reduce carbon emissions. It is possible to implement sustainable and energy efficient solutions keeping social, historical and cultural identity despite this requires specific technical knowledge from the professionals involved.

The analysis of the building renovation design projects demonstrated that it is not common to adopt an energy efficient renovation approach in Portuguese historic and old building renovation design projects. The documents analyzed revealed interesting building solutions although most common building solutions registered were not so different of conventional ones. The analysis made shed more light to the fact that it would be possible to implement even better and more sustainable practices and therefore get more close to the energy efficiency levels of the new buildings.

The study have demonstrated that despite the majority of the professionals consider the historic context of these buildings as a barrier there is an evident awareness of architects and civil engineers that is important to search for more know-how and training to implement sustainable, bioclimatic and energy efficient solutions in these type of buildings. However, they are also from the opinion that it is possible to adapt these solutions but it is fundamental follow a multidisciplinary approach between stakeholders, overcoming the gap between innovation and conservation or renovation.

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The Collective Self- Organized housing approach: improving the quality of life towards nearly zero energy strategies

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ABSTRACT: The paper illustrates the potentialities of the collecting self-organized (CSO) housing model as a growing strategy that can fulfill the goal of the 20-20-20 EU energy policies. Self-organized housing process - through which a group of homeowners carries out new construction and retrofitting projects on a district scale - reflects a raising awareness towards sustainability and the increasing self-managing capability of European society. This can lead to communities with a shared ideology and a strong communal life, such as in cohousing, where people choose to live in a residential community in shared services, green spaces, collective areas and low energy buildings. The reasons that lead to the co-residency is the necessity to find lost dimensions of social interaction, mutual support and good neighborly relations and at the same time a desire to reduce the complexity of life, stress and cost of managing daily activities. The sharing of goods and services can reduce living's cost as it reduces waste and optimizes external services (e.g. car-sharing, collective management).The main characteristics of a CSO approach are here examined, mainly considering participating design, local management, energy saving technologies, optimized energy sources at district level, moreover some realized case studies in Italy are analyzed. The paper is based on the first results of the research "*Proficient - SME network business model for collective self-organized processes in the construction and retrofit of energy-efficient residential districts*" (EU 7th Framework program 2012-2016).

1 INTRODUCTION

This paper introduces collective self-organized housing as it is plainly defined within the current PROFICIENT project "*SME network business model for collective self-organized processes in the construction and retrofit of energy-efficient residential districts*" (EU 7th Framework program 2012-2016).

Collective self-organized (CSO) housing refers to the process of a collective of individuals that organize, finance, plan and commission their own housing projects, (Di Giulio et al. 2012). As above defined, CSO projects require a certain level of community involvement, and a high level of participation in the project development process. CSO housing comprehends different typologies depending on the degree of communal or private living, self or collective organization, participation to the design and construction process as well as differing support from the local/central authorities. One of the first aim of the PROFICIENT project was to create a common background on the CSO, by providing a definition on the different typologies: Cohousing, Collective houses, Self Build Housing, Common Interest Community et oath. (Di Giulio et al., 2013). The above definition of CSO housing includes different forms of existing collective housing typologies and areas of application within, on the contrary the definition is selective enough for excluding the traditional forms of real estate development and all kinds of individual self-organized initiatives.

By assuming this, it can be said that the Cohousing is the higher level of CSO where the ideology of a communal life is quite strong: it can be defined as “a neighborhood development that creatively mix private and common dwellings to recreate a sense of community, while preserving a high degree of individual privacy” (Lietaert, 2010). The first experiment of cohousing was in 1964, when the Danish architect Jan Gudmand Hover with a group of friends tried to reproduce in the city some benefits typical of a village: an united community, shared spaces and services. Cohousing is today an emerging reality across Europe that involves thousands of people, especially in Scandinavia, Germany, The Netherlands, United Kingdom.

CSO housing can comprehend both new construction and retrofitting/refurbishment projects. Building process is generally issued by a group of non-professional clients that are the current (in the case of retrofitting) or future (in the case of new built housing) inhabitants of the project. As a result, they do not only have an interest in choosing the optimal solution in terms of investment costs, but also the energy costs and maintenance costs during the lifecycle of the project, (the total cost of ownership -TCO), should be an important part of their decision making process.

This trend offers opportunities for small and medium enterprises (SME’s) such as architects, engineers and contractors and energy service companies (ESCO’s) whose services are of use in a CSO housing project. Promoting CSO housing initiatives in urban regeneration or in developing new districts to become energy-efficient and more sustainable places to live means that SMEs’ business opportunities are improved. The community is considered as a collective of individual end-users that will be able to take initiative in design and building phase and/or steer their own collective energy-efficient and community-oriented housing project.

The aim of this paper is to disseminate the actual development of the work in the PROFICIENT EU FP7 project (2012-2016).

2 THE COLLECTIVE SELF – ORGANIZED HOUSING PROCESS

There are different reasons that can concur in starting CSO projects and, at the same time, different parties can be the promoters. The initiative can come from a municipality that wants to improve the quality of a neighbourhood or from a Housing Company to motivate inhabitants to contribute their own environment, or from a group of people, such as in the most examples of cohousing. The European cohousing landscape is becoming more diffused every year: new building communities, cooperatives, rural communes, self build centres are sampling of CSO typologies, which are emerging in all European Countries. (Senge 2008).

This category also manifests a wide range of types, from market-oriented projects whose main interest is housing production, to cooperative living initiatives. High ecological standards, quality architecture and good neighbourly conditions characterize many CSO examples, at the same time, the emergences of new stakeholders (cooperative or communitarian structures) makes it clear that interest is growing in self-organized projects that are thought to be capable in the long term of overcoming market – oriented housing approaches (Id22, 2012)

In Italy the CSO approach is in progress: models are mainly based on partnership among municipalities, housing companies and communities formed by renters interested in sharing services and expenditures. About 20 projects have been done in the last five years. Mainly they consist of a settlement of 20-40 housing units of different typologies (families and singles) created through a participatory planning process - where private spaces (homes) coexist with communal spaces (shared services).

2.1 *Decision making and project participation*

The project participation is a milestone of the CSO housing process that regards both the construction project, where the design itself has to facilitate contacts and social relations mainly focusing on energy-efficient solutions, and the community project. A participatory approach highlights the key role of the end-users [Figure 1.] Residents create communities and encourage neighbourhood engagement beyond the borders of their projects developed through cooperative planning and management. Ownership structures work against speculation and help affordability over time. This newer models, which collaboratively develop own housing environments, are meeting the architectural and social expectations of a growing diversity of user groups. This can lead to communities with a shared ideology and a strong communal life, such as in cohousing. The reasons may be founded in the aspiration to find lost dimensions of sociability, mutual aid and good neighbourly relations and at the same time the desire to reduce the complexity of life, stress and cost of managing daily activities.

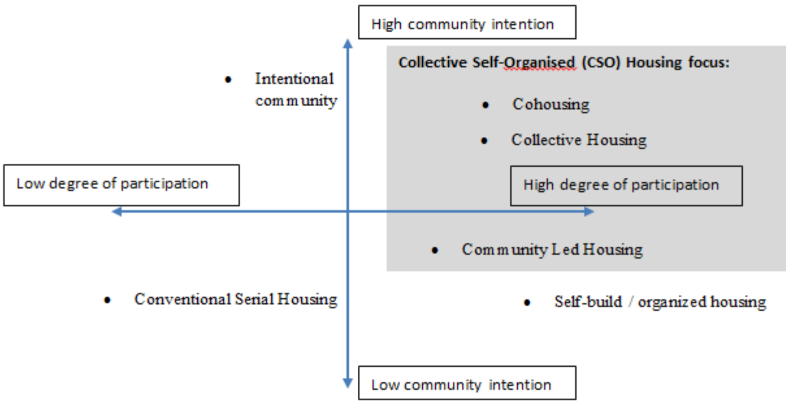

Figure 1. CSO process: degree of participation and community intention (Di Giulio et al., 2012)

What and how to share, how to manage services and common areas are decisions that have to be undertaken from the beginning by the community. Data coming from CSO housing experiences in Europe (Id22, 2012; Tamassociati, 2012), show that it is possible to save up to 15% of the average monthly expenditure per family: greenhouses, vegetable gardens, laundries, car parks, facilities, gyms, mechanic's workshops are the principal resources that are commonly shared within the community of co-inhabitants. But there can also be other services available within the community, depending on the initial collective decision-making process in which all participants must be convinced that the decisions taken are the right decisions and that they fit their individual requirements sufficiently, also regarding the personal financial possibilities and the time frame in which the project will be realized. This is strategic both for the architectural design and technical solutions both for coexistence rules. The most diffused self-organised housing processes typologies can be: group of individuals, co-operatives and joint product- service providers (Di Giulio et al. 2012). In the integrated design process, the re-use of the previous best solutions and the sharing of collective knowledge are essential to encourage interactions between actors. CSO housing can contribute socially, economically and culturally to neighbourhood. With respect to the architecture, this housing approach also offers solutions for disabled people, immigrants and those with lower incomes.

2.2 *The CSO process steps*

The process phases, from the initiative to the realization of a CSO intervention, can be relatively long. Generally the initiative starts from a community of people and the municipality favours the land's purchase initiative, providing a bonus of common surface and the investment costs of primary and secondary urbanization of the area. In the most cases the result is an interaction between the private initiative and the project of a public area/public spaces. But this should not be the rule, as it is very difficult to define a generic process flow.

However, common elements such as site selection, community forming, concept design as generic steps of the process can be commonly identified. [Figure 2]. One of the first aim of the PROFICIENT project is to define a common framework of the CSO process flow, providing a description of possible stages and steps, list and roles of stakeholders and procedures. The preliminary version of this framework is under construction. The aim is to use this framework as a basis for a specific CSO housing project.

The originality of a CSO project is represented by the fact that end-users are also clients that, in the most cases, act as an association, with collective and shared interests. This results in a great interdependency between all participants but at the same time the community of interests –

that begins in the land acquisition – sometimes fights with individual requirements and desires that are not necessarily in line with others.

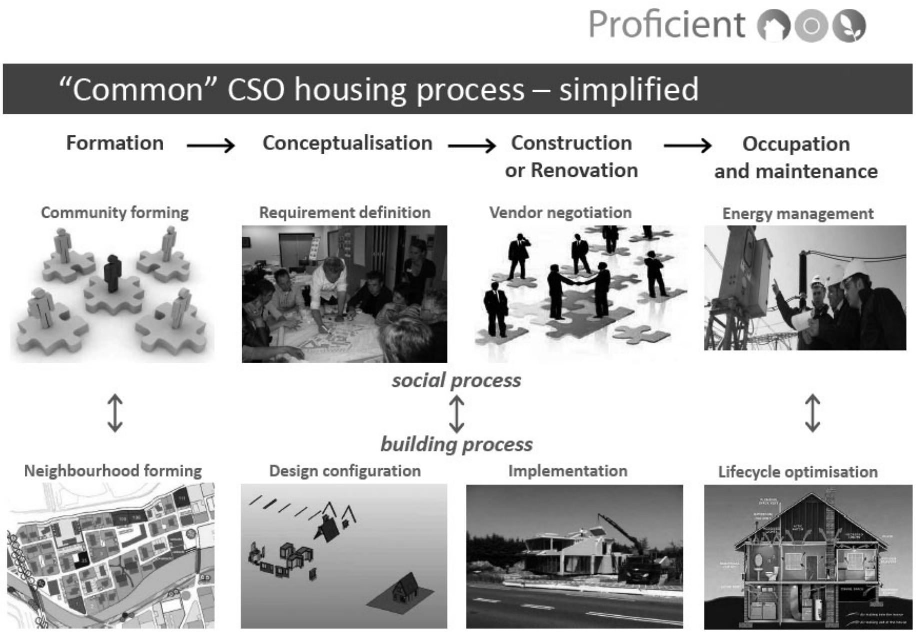

Figure 2: CSO Main process steps (Di Giulio et. Al)

The initial investment costs of CSO housing projects can be quite lower than for a traditional housing project. The land acquisition is generally lower, thanks to special agreements between associations and municipalities. Building costs are generally similar or higher, depending on desired quality level mainly in the field of energy efficiency needs that require high thickness of insulation and high efficient plants. Additional costs can be lower, due to the direct relation between project developers and clients (no need for support of intermediary such as real estate agents) or higher, depending on the grade of satisfaction of each individual subject. If one of the participants is not satisfied with the prospected outcome of the project, the requirements and decisions in the CSO have to be adjusted. This can result in delays, which in turn may lead to other participants stepping out of the process. By the way, a CSO project generally takes more time than other types of projects (about 3-4 years on average for collective self-organised versus an average of 2 years for traditional projects). The main reason can be found in the time required for community forming and the necessary dialogue in coordinate and organizing all the individuals requirements. Anyway, in the long – term period, costs are substantially reduced thanks to the lower operational cost and shared service costs.

2.3 *Social Aspects*

New target groups and lifestyles demand new housing and settlement forms. Conditions for realizing CSO projects result from an interaction of factors that make possible to enable social mixes. European cities like Freiburg, Tubingen and Amsterdam adopted in the last years the co-housing model, a great potential for developing sustainable districts. (Senge, 2008)

Common use areas may be: multi-purpose rooms, kitchens, laundries, guest houses, libraries, playrooms, workshops and warehouses. In addition, large open spaces such as gardens, vegetable gardens, courtyards, parking areas and sun terraces represent common open space for socialization. Thanks to these spaces also co-housers may have common facilities such as Gas (eco-supportive buying groups), babysitting, car-sharing and other. It is very difficult to define a common strategy of achieving common spaces, as there are many factors that determine their characteristics: end users' wishes and requirements, the complex location (rural or urban area), the type of project (renovation or new construction).

In the most cases CSO housing projects are based on the sustainability principles: energy saving and green buildings. There is a relation between social cohesion within the project or complementary lifestyles and ambitions on sustainability and energy-efficient buildings. Affordable and socially – designed homes are well designed when the community starts with clear and shared intentions from the beginning. Moreover, the social cohesion during the in-use phase of the project is strengthened when there are common facilities, such as common gardens, especially when maintenance is done by the community. One can get, in this way, savings and benefits are not only economic but also environmental.

3 THE CSO DESIGN

The demand of those who are seeking to satisfy their need for socializing, sharing, mutual exchange through the creation of innovative forms of neighbourhood units and more complex types of housing is emerging. Young couples with small children, single, immigrants, elderly people, work colleagues who share expenditures, are in particular social categories that express a widespread need for sociability (Id22, 2012).

In a CSO project, collective facilities and individual dwellings have the same importance as they are part of the same intentions and way of living. On the other hand, the individual houses are not necessarily of the same typology. In the most cases, CSO projects aim for a variety of people, lifestyles and age groups within the community: as a result, the different individual needs of the participants and the shared requirements of the collective facilities interact with each other in a multi-dimensional way. This interaction occurs both on functional aspects, as well as on technical aspects.

3.1 *Functional Aspects*

Functional aspects of a CSO project can vary a lot from a traditional housing project [Figure 3]. CSO is a settlement consisting of dwellings (rented or owned) and from services and open common areas. A CSO housing project pursues the objectives of good living and quality of life, by means of the design of public spaces and relationship, planning of the network of natural spaces. This can produce substantial variations in the traditional typologies, as an example apartments may not have spare bed room, because shared guest rooms are part of the collective facilities. Laundry facilities are also shared in the common house as well as a communal kitchen. This sharing of facilities means that the individual dwellings can be smaller, which in turn means that the price of the individual dwellings goes down (Dijkmans, T., Klerks, S., 2013). More details on cohousing opportunities can be found on the website of one of the demonstration projects in the PROFICIENT project: Lancaster Cohousing [http://www.lancastercohousing.org.uk/].

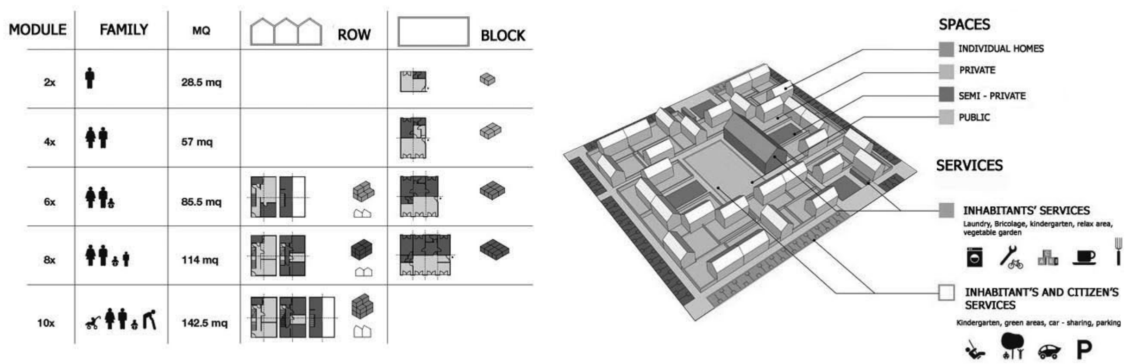

Figure 3: Functional principles of a CSO housing. Variation of typologies, mixing of spaces and functions, community (By courtesy of Tamassociati studio)

3.2 *Technical Aspects*

Climatic change is demanding attention on alternative energies. For this reason, the opportunity to co – producing energy and to optimize urban services is rapidly gaining in importance. Many status symbols such as independent central heating or cars are losing their value and people are showing more interest in saving money besides of qualitative living. How do the CSO projects can contribute to sustainable neighborhood and urban development as defined by social and ecological aspects is aiming to be investigated in PROFICIENT mainly in the Work Package 4 “Business case for technology solutions” which main objective is to identify the most effective technology solutions in the area of building systems and district energy systems and to prepare the most appropriate business case to make SME implementing these technologies on a large scale. The focus is on exploring driven technologies and services that are transferable to the district level (building and on long term economic, social and environmental effects) imprinted on long-term economic and cost-effective solutions.

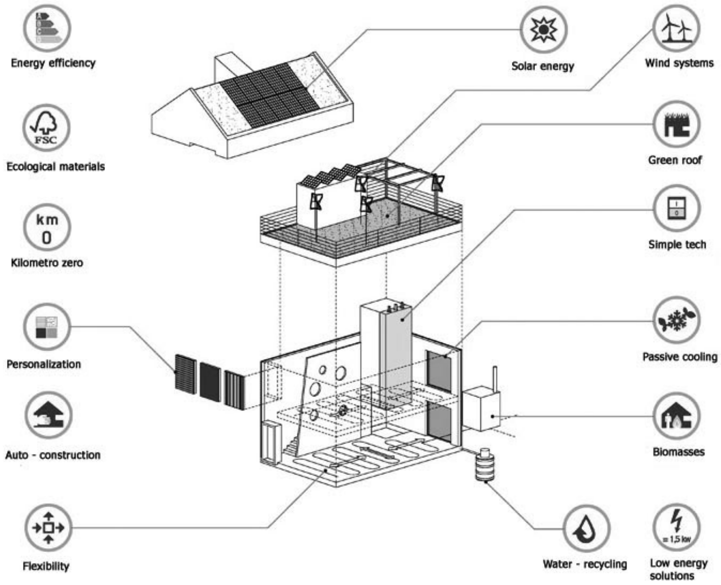

Figure 4: Sustainable opportunities for CSO housing projects (By courtesy of Tamassociati studio)

A CSO housing project pursues the following objectives of sustainability[Figure 4] :

1. Energy efficiency (Energy self-sufficiency- Use of renewable energy- Zero carbon dioxide emissions- Use of low-impact materials and at km 0- Adoption of strategies for recycling and recovery of materials and waste);

2. Sustainable mobility (Support for public transport- Support of pedestrian and bicycle mobility- Support of alternative services such as car-sharing).

By starting from an analysis of regional experiences and knowledge on existing CSO projects, the aim of WP4 work is to gain information about different practices and to define the target for new and optimized business cases, to give an overview of available energy efficient technologies, allow their parameters to be changed and allow a concept design to be modelled, based on the requirement of the different participants. Finally, a decision tool based on a scenario analysis of Total Cost of Ownership (TCO) will be developed to support the selection and implementation processes of the most cost-effective technology solutions to meet dynamic performance requirements, to provide insight in the consequences of ambitions on energy performance, in terms of costs as well as spatial limitation. The analysis will be carried out through two different evaluation systems: a benchmarking analysis (single criterion) and the interfacing of criteria analysis (multi-criteria).

Different possibilities to apportion collective costs and therefore make an early estimate of the individual and collective costs, will be targeted during the PROFICIENT project. In a decision support tool based on Total Cost Ownership, the collective TCO could be calculated, anyway the apportionment of these TCO would be required to determine each individuals’ combined TCO: the individual TCO of his house and a portion of the collective TCO of the project (Dijkmans, Klerks., 2013).

4 A CASE STUDIES IN ITALY

In Italy, examples of a design for new ways of living, more social and more shared are in growth. Tamassociati studio [http://www.tamassociati.org.] is one of the most active in the fields of sustainable architecture, urban planning and participatory processes. Two examples that can be considered as innovative design process with new meanings and possibilities for people, in accordance to spaces towards zero energy impact architecture, are below examined.

4.1 *Cohousing "Quattropassi", Villorba (Treviso)*

The project was promoted by the Cooperative "Pace e Sviluppo" active in the context of fair trade and in raising awareness about the responsibilities and the value of consumption and saving. The participative plan involved 8 families in the North of Italy, in the little town of Villorba, near Treviso.

The inhabitants choose each other on the basis of some common goals: open spaces are the heart of the eco-village and have a central role of social and quality of life, covered and uncovered common spaces are managed collectively. The project is divided into three different levels: the urban scale (the eco-district), the domestic scale (the eco-home) and the neighbourhood scale (the cohousing).

Buildings are placed in the lot according to a principle of settlement which has as reference the village of the local tradition (as the current local legislation prescribes) reinterpreted in a contemporary way. All the elements of the project (buildings, parking and paths) are placed on the borders, in order to preserve as much as possible the central green as undivided space, which is that is the cornerstone of the eco village [Figure 5].

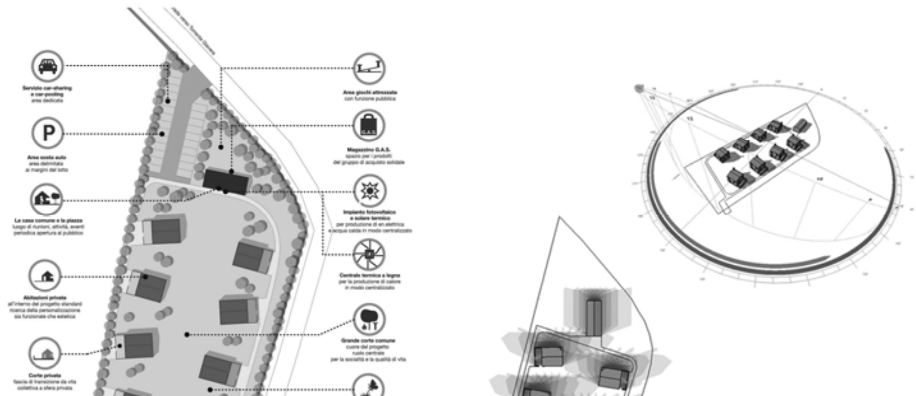

Figure 5: Plan of the intervention. PROJECT DATA: Surface area: 6.678 m^2 Building area: 654 m2 N of dwellings: 8 Collective building area: 230 m2 Building cost: 1.350.000 € Total cost (comprehensive of area): 2.000.000 € Realization period: 30 months 2010-2013 (By courtesy of Tamassociati studio).

Car traffic is outside the zone: within the area people move on foot or by bicycle in a protected space, quiet and safe suitable for adults and children. A common building is the heart of the cohousing community. Besides of common rooms for meetings, relax and kindergarten, here are also leased a large storeroom in the basement, technical rooms for the centralized system, solar collectors and photovoltaic panels on the roof. The basic typology is rectangular detached houses, two floors high, in three versions differing in size, depending on the needs of different families. Each house is characterized by: invariant elements - stairs and services - and variable elements such as inner walls and partitions. By using a modular plan, that allows variations on the same typology, it was possible to agree with the single family the desired arrangement of the dwellings. The same principle has been applied on the fronts composition. An unified language characterizes the intervention, in view of the general coordination of the overall project and in a dialectical relationship with the context in which it is inserted. Each modification on the facades' design was decided by mediating global coherence and individual needs.

In terms of sustainability, the project meets high standards of resource conservation, use of environmentally friendly materials and renewable energies.

Particular attention was given to the envelope solution, choosing a thick masonry clay blocks, with air cavity for summer ventilation. This system meets the following criteria: environmental compatibility of materials, simplicity of construction, strength and durability, low transmittance, thermal inertia, breathability, insulation, cost containment, passive ventilation in summer [Figure 6]. The plant is a centralized biomass heater (pellets) located in the common building. The boiler is coupled to a thermal energy storage tank, to prevent problems of high temperature during periods with reduced demand of energy. The tank is also thermal storage for domestic hot water from solar collectors. Photovoltaic panels 8 kW power are installed on the roof of the common building instead of each home: this optimizes and lower the total cost of the system.

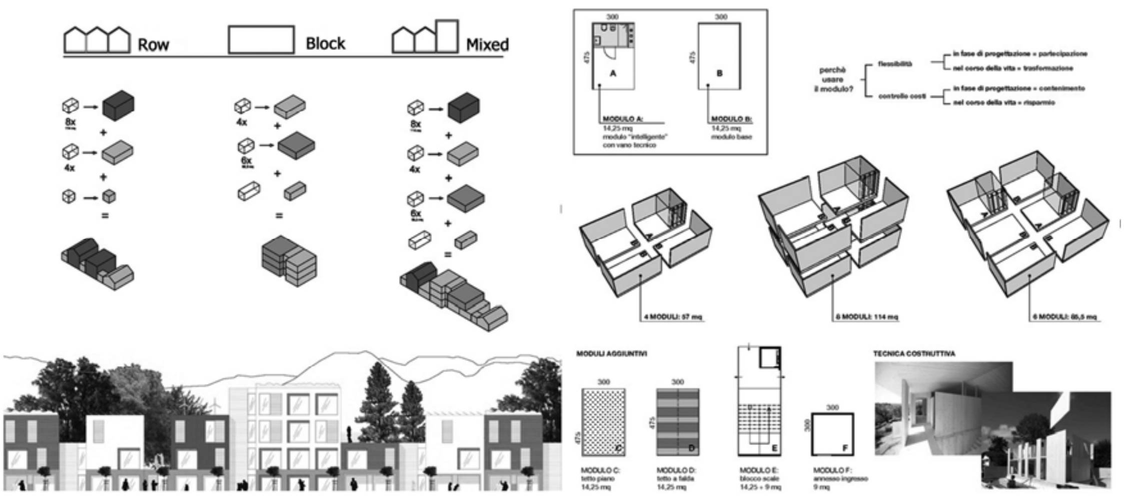

Figure 6: Typologies and building system study. Each modification on the facades' design was decided by mediating global coherence and individual needs. Different typologies and function are mixed together (By courtesy of Tamassociati studio).

4.2 *Cohousing "Mura S.Carlo", S. Lazzaro, Bologna*

The project is located in the village of S.Lazzaro near Bologna and comprehends 12 apartments. It has been promoted by the association E'/co-housing, which has been in contact with the Municipality of S.Lazzaro to find a lot of 2000 square meters to achieve a cohousing project mainly focused on energy-efficient and socially sustainable policies.

The municipality has adopted this instance and issued a tender for the sale of this land. In this case, the municipal administration has favoured the initiative as part of a project of social housing, providing a bonus of common surface and the investment costs of primary and secondary urbanization for a park adjacent to the lot. The result is an interaction between the private own interest and the public administration initiative to promote social projects and green areas (e.g the project of a public park nearby), moreover the virtuous process of urban regeneration is the result of a replacement of an old building, that was demolished.

The new complex consists of a 4-storey building with 12 apartments and a variety of shared outdoor spaces and common services: activities common room, laundry room, music room, crafts room, bicycle area, bricolage room, and bicycle laboratory. Common activities are mainly located at the ground floor, to allow direct access to public life and its use even to the neighborhood residents [Figure 7].

Main structure is timber-type Xlam, a very high – efficient envelope with minimum transmission losses [Figure 8]. The heating system involves the use of renewable energies to cover not only the thermal energy required to heat the domestic hot water but also heating. Three technologies are used: a heat pump fed by electricity, gas fired boiler, and solar devices (solar collectors for domestic hot water and PV systems).

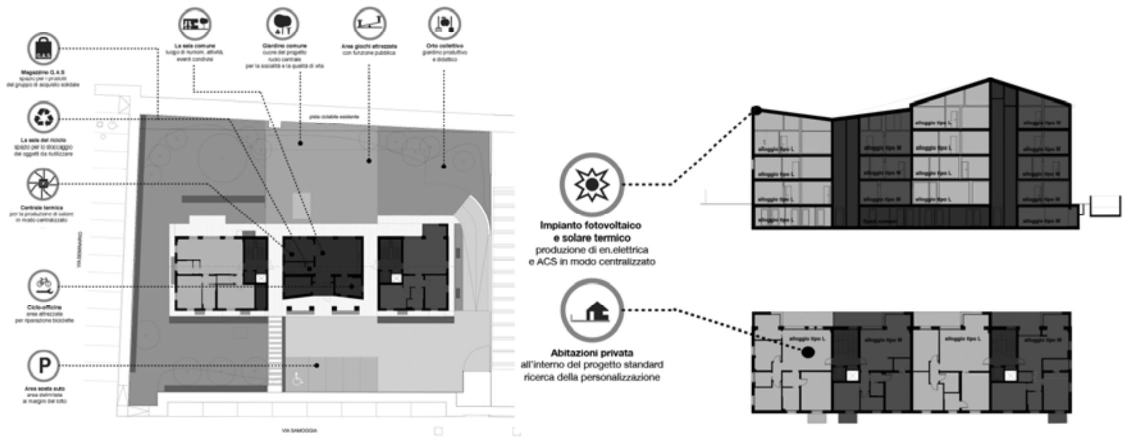

Figure 7: Plan and section of the intervention. PROJECT DATA Surface area: 2.000 m^2 Building area: 1000 m^2 N of dwellings: 12 Collective building area: 250 m^2 Building cost: 2.200.000 € Total cost (comprehensive of area): 3.300.000 € Realization period: 30 months 2011-2013 (By courtesy of Tamassociati studio).

Figure 8: Virtual Image of the intervention (By courtesy of Tamassociati studio)

5 CONCLUSIONS

The CSO housing process steps, as they are being defined in the PROFICIENT project, needs to optimize a decision support tool based on TCO as a decision making process having the most impact in the early design stages.

An early stage decision support tool is being defined, to support the community forming process by providing an estimate of the financial consequences, in terms of TCO, of proposals that are made (building site selection, district energy solutions, pre-design of the collective and individual facilities (based on input provided by the CSO housing community), available energy efficient technologies, concept design to be modelled (based on the requirement of the different participants). This should be a dynamic process, where a member may be lost and one may join later, that requires a deeper interaction between the needs of the community and each individual client.

Moreover, a “cost-optimal” approach for calculating the economic optimum for energy saving measures is being defined. By following the Energy Performance in Building Directive

(EPBD, that requires for cost-effective solutions and a cost-effective result that relates to the energy performance level which leads to the lowest cost during the estimated life-cycle), the most appropriate business case for SME's to implement efficient technologies solutions on a district energy systems large scale is being prepared. The work focuses on the typologies, market analysis and delivery models of the energy efficient collective self-organized housing sector and its implication on SME's is to identify the scale and structural characteristics of the energy-efficient CSO housing market.

The collection of experiences and knowledge of existing CSO housing projects or similar projects at local, regional and EU level allows to gain information about different practices and represent the basis for the following development processes. CSO housing model is a growing strategy that can fulfill the goal of the 20-20-20 EU legislation thanks to the smart energy policies at district level, the sharing of goods and services that can reduce living's cost during the overall life cycle.

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Technologies, strategies and instruments for energy retrofitting of historic cities.

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ABSTRACT: The buildings in the historical centres of small to medium-sized towns throughout Italy are generally constructed with homogeneous technological characteristics based on their geographic position and have specific cultural values.
With regard to retrofitting there is a high demand for the integration of energy saving systems especially in light of the economic crisis.
These elements conflict with the public administration's responsibility to preserve listed buildings and cultural heritage artefacts and their regulatory.
Another issue we have to address is the economical one, in particular the one referred to homeowners' need to install these systems in order to save on their electricity bill.
We need to analyse these aspects because of the numerous variables involved in energy retrofitting operations in historic buildings using appropriate systems and software.
The objective is to define possible guidelines in the field of retrofitting of historical buildings also analysing practical examples and case studies in the Italian territory.
In this regard it is necessary to look at the issue from a technical managerial and economic point, taking into consideration the technology used and financial and economic instruments for private sector housing.

1 INTRODUCTION

Minor historical town centres in Italy are characterised by a built and social fabric with common and similar characteristics. Depending on the region, north, centre or south, there are distinctive and common connotations at the architectural and morphological level, which strongly characterise the context of reference and contribute to the definition of a precise identity at local level.

The populations living in minor historical town centres consist mainly of the lower middle and middle classes. The average user group of small towns, which at one time were much more homogeneous in terms of social and cultural characteristics, today has connotations that are very different due to the migration that has taken place the towards small towns from the major cities by the middle class who once resided in urban centres but who have been progressively impoverished by the economic crisis. This population, no longer able to bear the costs and dynamics of the big city, find in small towns a more comfortable and affordable place to live.

The built heritage of the small towns, while often retaining valuable characteristics in terms of cultural and landscape value, does not respond adequately to the needs of energy efficiency required by current legislation. These are buildings, above all with reference to residential buildings, which also require periodic and widespread maintenance.

Over the past decade, because of the evolution of the environmental emergency, there has been an increase in the number of households that pay particular attention to the issue of energy saving and the containment of consumption, as well as to the production of energy from private plant for their own exclusive use. Thanks also to the incentive system introduced in Italy, the dissemination of technologies related to solar thermal and photovoltaic has seen a major growth in recent years. This growth has also involved a greater awareness on the part of the middle class regarding the issue of energy production. A growing interest has also involved the resident population of the historic dispersed fabric of smaller towns, especially with regard to the possibility of installing solar thermal and photovoltaic plant, about whose benefits in terms of saving energy and money, the average user has gradually acquired more and more information.

The willingness to redevelop, also in terms of energy, the built heritage of the historic centres is contrasted, however, by the difficulty in being able to make a choice about what is the best solution.

Different aspects contribute to this difficulty, resulting from the intersection between the peculiarities of the building fabric in question, the characteristics of the resident users and the solutions proposed by the operators in the market. To this is added the limitations imposed by regulations from the public administrations in terms of landscape protection, which tend to preserve the heritage of the historic centres from high-impact operations in a general sense.

2 HISTORICAL DISPERSED BUILDINGS IN ITALY AND THE QUESTION OF ENERGY ISSUES

2.1 *Protection and energy retrofits*

The housing stock of the dispersed historic centres in Italy is generally composed of buildings with important characteristics from a historical and architectural point of view, and is constrained by the tools of landscape protection insofar *as it is a complex of buildings that form a characteristic view that has aesthetic and traditional value* (Article 136 Legislative Decree No. 42/04 - Code of Cultural Heritage and Landscape).

From this point of view, the activity of protecting historic centres, as stated, for example, in the technical norms of implementation of the Landscape Plan of Lazio Region, is directed at the maintenance of "*the physical integrity through the conservation of the heritage and historical fabric and of the views to and from the old town centres also through the prohibition of transformations which are prejudicial to their safeguarding*".

With reference to operations of energy retrofit, this notion of protection involves the prohibition of a whole series of operations of installing technological systems of a visible type for energy saving.

These devices, in fact, involve a visual intrusion on the building which, if not controlled, might lead to a depreciation of the overall image of the historic town centre as it has been established over time.

The urban fabric of these settlements (minor historical centres), in fact, still has a strong historic and architectural value due mainly to their typological constructive characteristics and obviously unitary materials and which are still clearly evident and of strong visual impact.

The type of construction of houses is that which is typical of the Mediterranean area, characterised by buildings of medieval origin, with a masonry structure which can also be irregular, sometimes with conserved facing with high thermal inertia with wooden roofs and wall tiles.

The chromatic and material totality of construction materials and finishes used provides that identifying character of the historic centre that leads the authorities responsible for their protection to assume conservative attitudes and strong suspicions regarding the installation of the most widespread technological devices: photovoltaic plant, micro windmills or solar collectors.

The demand for technology implementation for the purposes of energy saving by users in fact requires the presence of high-impact technologies both from the point of view of visual intrusion and the storage of the technical elements of the building to which the regulatory instruments of protection recognise a documentary value and which, in retrofit operations, could be replaced or partially modified.

Upgrading energy efficiency in these settings, which make up a large part of the inhabited fabric of our country and which, in recent years, because of the economic crisis, have seen a substantial increase in population, it is not supported by any regulations specifically regarding energy retrofitting.

The tools of landscape protection provide only sparse and generic information without any guidance on the most appropriate technological choices.

To this has to be added that the few indications in national legislation relating to energy savings and energy upgrading of existing buildings, in the case of listed buildings, only provide the possibility of derogation from the requirements of the law.

This is an operation that relegates the requirements of energy saving, compared to the protection of the building, and allows for a wide margin of discretion on whether or not to adopt such systems.

The result is that the authorities responsible for the protection do not accept the insertion of visible plant in historical contexts and proposals are in fact delegated to the sensitivity and training of the professional planning the retrofit project.

A planner who does not always possess valid tools to assess the alternatives available.

2.2 *Building and users. Typological and constructive characteristics in relation to the energy issue*

Following the widespread recognition of the urgency of environmental issues, the concept of energy efficiency and energy upgrading, is interpreted and altered in architecture as a fundamental prerequisite and goal to be pursued. A renewed design is required now that is able to ensure indoor environmental quality through the means of technical-innovative construction.

By energy-efficient building what is meant is a building structure that can guarantee inside a state of wellbeing and in which, by minimising the use of non-renewable energy sources, the achievement of thermal-hygrometric, acoustic, lighting comfort and indoor air quality, are not delegated exclusively to the plant, but are obtained through appropriate environmental, typological and technical-constructive solutions.

The awareness on the part of an increasing number of planners and users of the urgency of environmental and energy issues has allowed, in recent years, the building and redevelopment of buildings with high energy efficiency. This is the result of a slow cultural evolution, which began in the late ‘60s, with the first solar buildings, and developed over the years, up to the development of integrated design strategies, innovative technologies and high-performance envelope systems.

It is essential today to focus above all on upgrading the energy efficiency of the heritage of historical buildings that too often and for too long has been neglected and which are in need of “progress” in energy terms precisely because they represent a large-scale reality in many Italian cities.

In fact, the movement of people into buildings of the historic fabric, with the encouragement of the incentives provided by the various editions of the Energy Account, has led to a growing demand to include systems for energy saving in traditional housing.

We must therefore consider a type of user which is profoundly changed and diversified compared to the one that has been present until today. In fact, in Italy as in most of Europe, research has been conducted and pilot projects carried out on the redevelopment of the residential social housing stock, in many cases on publicly owned property. The field of social housing has been the subject of experiences and experiments for several reasons: to try to provide a solution to a problem of obvious social emergency, for the possibility to manage the redevelopment of the built environment with a single large owner, avoiding the obstacles arising from the fragmentation of the property, to make it easier to try technological and managerial solutions in the absence of historical restrictions.

In fact it should be noted that the stock of historical buildings in our country has in many cases similar characteristics, whether referring to multi-purpose building or diffuse residential housing, and these similarities can be found not only in the morphological-constructive characteristics, but also in the characteristics of the user group of reference.

It is a fragile though solvent class, that which acquires bargaining power in small towns but lives in conditions of economic hardship in large cities. This type of user, who makes up the new lower middle and middle classes in the Italian social fabric, is characterised not only by cultural and social heterogeneity, but it is united by the need to reduce their energy costs.

Reducing energy costs also involves rethinking the way in which the energy service is offered. This question should deal with the capability to choose the technical and technological solutions, the means of operating the service and the related economic and financial aspects, with the most appropriate choice, which too often translates into measured and timely interventions usually resolved in the replacement of traditional fixtures in favour of others with high energy performance, the installation of solar collectors and photovoltaic panels.

These interventions are designed as plant operations to be superimposed on the building and not as operations of upgrading energy efficiency that can provide the same with added value especially from the point of view of architectural quality.

The desire to pursue energy efficiency at all costs has often led to solutions of low architectural quality and the standardisation of building types that are correct from an energy point of view but architecturally not very convincing or effective.

The trends in the construction industry can be divided into two types:

a) that of current building, which sees the integration of elements and plant systems in the envelope or façade. In these cases, the solution most often adopted for upgrading interventions on the built is that which sees the inclusion of photovoltaic panels or solar collectors, with scant attention to architectural quality;

b) that relating to high-level design experiments of exemplary value, where the quality of the experimentation goes hand in hand with architectural quality.

The challenge for today's architecture in the field of upgrading energy efficiency is not to be limited to the application of energy-saving systems through added installations, but the declination not only in terms of technology and performance, but also artistically and figuratively.

3 INSTRUMENTS AND TECHNOLOGIES FOR ENERGY SAVING

3.1 *Materials and innovative technologies for energy saving*

In the setting of diffuse historical buildings the intensification of the activity of redeveloping and "management" of the real estate stock in terms of energy efficiency, sustainability and urban well-being measures the real regeneration of city centres; activities which are flanked by interventions of conservation or restoration for those contexts of particular value which are affected by restrictions to protect the landscape. An approach to the project which is as attentive as ever to the energy upgrade of buildings but which, at the same time, suggests a protection of the particular cultural value of those nuclei of urban settlements of high environmental quality and historical importance.

Finding ourselves operating in the area of the life cycle of historic buildings, the success and difficulty of the project thus consist in the ability to communicate with the technological and plant qualities that that the building already offers and which, in each case, will be preserved, enhanced or integrated.

The multiplicity of adaptive interventions on existing buildings affects different parts of the building and today has to deal with today, in compliance with the current regulatory framework, solutions, methods, technologies, innovative materials and certification systems that redefine, in a new synthesis, the concept of quality in the planning intervention.

The interventions aimed at enhancing the energy efficiency of historic buildings can be traced to three main operational strategies that can simultaneously find a reference both in the market for new constructions and renovation. In particular:

1. Reduce heat exchange with the outside of the building and reduce energy consumption and non-renewable natural resources;

2. Introduce innovative plant components with a high technological value, low enthalpy and which serve as sources of renewable or recoverable energy for the functioning, production of heat, heating and cooling.

3. Adopt technical solutions, materials and certified products that meet the requirements of the environmental and energy certification protocols, and that represent the quality parameters measurable by the quality achieved and the sustainability of the construction.

The first category refers to the adoption of all the technical solutions for the building envelope provided by the current construction market, which can improve the thermo-hygrometric characteristics of the vertical and horizontal, opaque or transparent components which bound the heated volume.

The recent Legislative Decree no. 63 of 4 June 2013 transposes European Directive 2010/31/EU on the energy performance of buildings, the so-called “nearly zero energy building” Directive.

Altering Legislative Decree 192/2005, the Law by Decree introduces the new national methodology for calculation and the minimum requirements for the energy performance of buildings, and provides for facilitations for energy upgrading that involves existing buildings of all cadastral categories and those interventions that enable the achievement of an annual energy demand for winter heating not exceeding the values defined by the Ministerial Decree of 26 January 2010.

The activities of addition and substitution indicated in the Decree define the different operative strategies that can be pursued, while the distinct performance responses are defined by the climatic zone in which the building is situated. According to different design assumptions it will be possible, on the one hand, to define the modalities of integration and the thickness of new insulation in the facades, envelope and intermediate floors, and, on the other, to move to the replacement of windows that do not satisfy the transmittance values required by national regulations.

The particular connotation of certain historic buildings and their intrinsic cultural value directs the creation of false internal walls through dry solutions involving the juxtaposition of plates glued or attached to a frame that incorporates a layer of insulation in the cavity thus formed. This solution favours the respect of the existing architectural external image without having a significant impact on the existing structures which in this case would not be significantly stressed. A disadvantage would be a partial reduction of the internal areas and the limited elimination of thermal bridges on the façade. In the case of deterioration of the external surfaces it will be possible to replace only the exterior plaster and individual decorative characteristics of the façades without distorting their original impact on the context of their setting. A worthwhile alternative technique to the internal false wall is instead the realisation of a ventilated external “coat” consisting of an exterior insulation and a ventilated air chamber inside a substructure of stanchions and beams which support the lightened concrete slabs of the exteriors. The slabs are reinforced by a glass fibre mesh and subsequently have a thin plaster finish applied, not unlike the original traditional solution.

On the envelope, the usual maintenance of the protective mantle, or of the coverings in the case of inclined envelopes, can be combined not only with the increase of insulation, but also to the realisation of a layer of ventilation which considerably improves the level of thermo-hygrometric comfort of the closure without changing the surface appearance.

In the absence of specific landscape restrictions, national regulation provides for the possibility of intervening with the demolition and partial or total reconstruction of buildings allowing a total redefinition of the technological choices for the envelope and the structures; this last solution is clearly an intervention of great economic significance.

In both cases, different financial arrangements, updated annually, provide incentive formulas for building interventions aimed at improving energy efficiency of existing buildings through the partial tax deductibility of the costs incurred. The facility consists of a deduction from the gross, both IRPEF and IRES (personal and corporate income tax), of an amount equal to 65% of the costs incurred up to a maximum of €153,846.15.

Among these interventions is the adoption of plant solutions listed in the second category above. The most widespread example is that of the integration of solar panels to produce hot water or photovoltaic panels and amorphous films for the production of electrical energy from the envelope, or the replacement of all or part of the winter climate control systems with plant with condensing boilers. The special character of the settlement context and the precarious economic conditions of private individuals do not provide for easily implemented energy generation solutions on an urban scale which instead would allow a substantial reduction in the cost to users for energy and would reduce the impact resulting from the installation of solar collection modules.

This solution, although desirable, requires financial planning and a significant amount of initial expenditure that can be sustained only by enlightened public operators, or private monopolies attracted by the effective convenience of the intervention, along with financial support for the total reconstruction of energy distribution networks which would only be only sustainable with substantial financing.

Interventions on the energy efficiency of buildings are in general accompanied by the introduction of solutions that take into account the sustainability of the production process.

Through energy and environmental sustainability certification, the principles of environmental sustainability translate into a significant opportunity for the renewal and transformation of normal building practices both in the planning stage as well as during construction and operation.

In light of this new opportunity, businesses - at a time when the market has significantly shrunk - are called on to invest in the research and development of products targeted at energy and environmental sustainability, products and building systems that use natural or low absorbed energy materials for which it is fundamental to attest to their objective certification of conformity and environmental quality.

4 THE MANAGEMENT OF THE ENERGY QUESTION THROUGH GIS SYSTEMS. PROBLEMS AND POTENTIALS

4.1 *Management and control of GIS data at the level of building and territory*

The management of a problem of energy supply cannot be separated from an initial assessment the needs and capacity or cost of the supply itself. It can be deduced how the possibility of producing in situ energy is the most economically advantageous solution that has least impact on the urban fabric. The problem remains of the protection of the built, both from an aesthetic point of view and from a static/structural one to evaluate the effective residual bearing capacity of roofs in the specific case of photovoltaic systems.

The first step for a geostatistically correct approach, which allows the creation of an efficient tool for the evaluation of the economic viability of the project and the design itself, is to inventory the data related to a building with indices that describe its structural state and energy requirements (also in relation to the period of the year).

The same approach will have to be taken with the existing network of energy distribution, considering the technical-economic possibility of a hypothetical strengthening to satisfy the needs required.

At this point it is possible to map out the condition of needs and capacity to procure energy for a core of buildings; whenever a condition of homogeneity between adjacent blocks of buildings occurs it will be possible to assess the problem in a unique way, ensuring uniformity in the design to the advantage of the planning cost-quality relationship.

The basic idea is to avoid the spreading out of mini plants scattered over a number of roofs, without an idea of overall design, and evaluating the possibility of using surfaces even if they are not present in the immediate vicinity, taking advantage of existing networks and logistics.

The methodology of work follows a survey of the multicriteria type managed through a GIS tool that will compare data derived from the analysis. The data brought into play in the proposed methodology will have to be summarised and correlated in line with exacting processes of reading and archiving.

The choice to work with a geographical GIS database stems from its ability to use different tools for the cataloguing and numerical management of the building that is subject to the intervention. The system allows spatial operations on multiple data that define an area of land, evaluating them together with data for aesthetic-landscape, historical-economic, demographic-cultural, and technological aspects, without of course neglecting all the regulatory and restrictive aspects present.

The proposed spatial database combined with a set of spatial functions and algorithms that will be designed and created in this project will allow the creation of decision-making models which will not be conditioned by the background of the “decision-maker” thus lowering the risk of subjective error, which very often is recurring in a subject.

The goal is that of creating an IT support that systematically analyses the data that characterise a problem, proposing a series of alternative solutions arranged according to values and weights strictly dependent on the context under analysis.

5 CONCLUSIONS

Retrofit operations on historical buildings have been conducted to date with isolated interventions and solved on a case-by-case basis. The result of these experiments is an extensive array of literature on the solutions of wall insulation and sealing glass walls, but little attention has been paid to large-scale management and of large segments of urban centres and, above all, the complex management of data and the variables involved with appropriate IT tools.

The assessment that is made on the intervention on the built was said to be related to judgments characterised by a high degree of uncertainty. What “is beautiful” or “architecturally correct” on a historical building is a judgment that is difficult to support with objective parameters.

We can measure the degree of efficiency of the plant and its cost, but which parameters and instruments that might be used are best suited to support the judgment of the technicians involved? The purpose is to create a useful tool both for users and public administrations in order to measure and therefore assess the level of compatibility between the need to upgrade the urban centre energetically and to safeguard its special characteristics in terms of consistency and documentary value.

This instrument has to provide the ability to effectively assess, in quantitative as well as qualitative terms, to what extent the introduction of elements and technologies for energy efficiency impacts overall.

Overall impact means not only understanding to whatextent the historical asset is changed in a negative sense (considering the impact of elements that are not in line with the nature of the asset in terms of visual appearance, etc.), but also emphasising to what extent the introduction of the changes are a reason to enhance the asset for a variety of reasons.

For this reason, both aspects (data) regarding the energy efficiency implementation as well as those relating to the aspect of the protection of the asset will be compared, in an attempt to understand which is the ideal point of intersection between the two.

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The inhabitable greenhouse

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ABSTRACT: The inhabitable greenhouse as a building type has relevance as we seek new ways of constructing and running buildings without the use of fossil energy. The present demands of airtightness, mechanical ventilation and heat recovery are relevant in relation to energy optimizing, but ought not to stand alone. The inhabitable greenhouse offers a different framework for creating "a good life" with a variety of sensual experiences in close connection with the seasons, greenery and the elements of nature. The research is a case study of a single-family house in Denmark built as an inhabitable greenhouse. Thispaper investigates the climate of the greenhouse with focus on overheating and humidity. The hypothesis is that the inhabitable greenhouse is a building type that offers a stimulating setting for "a good life" in combination with diminishing the use of fossil energy.

1 INTRODUCTION

The idea of living in a transparent, protected environment in close relation to greenery and the elements of nature is a well-known conception of the 20th century. Especially in the Northern hemisphere where we have seen projects from Buckminster Fuller's domes to experimental houses in various scales. The breaking awareness of the climate's vulnerability has initiated new ways of living "a good life".

Daylight is nature's main source of energy and crucial to people's quality of life. In Denmark there are big seasonal differences which cause a significant variance in the quality and length of daylight throughout the year. The length of day spans from more than 17 hours in summer to less than 7 in winter. Wind, rain and cold tend to keep people inside during the dark months.

"Sunlit buildings save lives. This is no idle claim. The evidence is there. Patients in hospital wards suffer less pain and are less likely to catch infections if they can see the sun. Heart attack victims stand a better chance of recovery if they are in sunlit rooms. Depressed psychiatric patients fare better if they get some sun while in hospital, as do premature babies with jaundice. We all benefit from being in a sunlit environment to some degree. Unfortunately, our buildings, our streets and our cities are not as sympathetic to sunlight as they might be." (Hobday31st December 2006).

The inhabitable greenhouse offers a framework for living where the inhabitant will be encouraged to spend time in a sunlit environment that is protected from the wind by the semi-open glass skin of the greenhouse. The glass allows most of the infrared radiation, which has known therapeutic effects (Hobday 15th May 2013).

Cities and buildings are organized and designed to fit with a given place and climate where they make the physical framework for people's life. Traditional architecture offers a great variety of fine solutions adjusted to climatic conditions. However, during the twentieth century, the way of climate adaption has faded into the background as it becomes more about achieving a standardized indoor temperature of 21°c in all rooms, all year round, no matter the time or place. Through this standardization, cities and buildings tend to indicate that people are considered to be homogenized and not treated as individuals with different needs shaped by the local climate and culture. This demand on a standardized indoor climate and a homogeneous constant temperature in all rooms of the dwelling has resulted in enormous energy consumption concerning both heating and cooling.

The Danish building regulations now demand that mechanical ventilation is installed in new house building in order to ensure that the achieved airtightness does not lead to an unhealthy indoor climate. One arrangement results in another. In this sense sustainabilityis simplified to insulation, airtightness, mechanical ventilation and heat recovery. These features are very relevant, but seen in isolation they do not automatically generate a heightened quality of life.

The inhabitable greenhouse offers a variety of different climatic conditions which are closely linked to the characteristics of each season. In relation to climatic adaption it is especially fulfilling the desire forsunlight in the darker months. The greenhouse itself protects the insulated inner dwelling from the wind and related cooling and thus has energy saving potential.

2 CASE STUDY OF TORKILD KRISTENSEN´S HOUSE

2.1 *Research methology*

Face-to-face interviews with the inhabitant, observations and measurements over a period of 1 year. Temperature, humidity and daylight are registered from 18th June 2011 08:00 to 18th June 2012 07:00.The data loggers are placed in 5 different circumstances to obtain a varied picture of the climate.All measures are recordedand represented in Danish summer time.

Unit A: Greenhouse, by the south wall of the dwelling 1 m above ground
Unit B: Greenhouse, by the north wall of the dwelling 1 m above ground
Unit C: Greenhouse, by south façade of greenhouse 1 m above ground
Unit D: Greenhouse, on the roof terrace 4.5 m above ground
Unit E: Dwelling, livingroom, 1 m above the floor

The measurements are compared with data from the nearest weather station in Aarslev.The measurements have been analyzed with focus on overheating and humidity. The results of the measurements have been compared with the interviewees' experience of living in the house and possible divergences have been identified. The purpose of combining the qualitative research interview with measurements is primarily to clarify to which extent the behavior of the inhabitant affects the climate within the greenhouse.

There are some uncertain parameters that need consideration. For instance, if the inhabitant has been away from the house during longer unspecified periods then the air intake has not been regulated. It has been discovered that theglass door in the facade has been continuously open to give room for the garden hose as well as a new opening for the dog, which may explain a divergence between the inhabitant's impression of how low the temperature can be and the measured temperatures below zero. Finally, if the house was inhabited by more than one person, the measured level of humidity might have been higher.

2.2 *Background and motivation*

Torkild Kristensen:"It all started, as I was in Portugal. How can I bring this home with me?"(Kristensen 4thJune 2013).

The house of Torkild Kristensen was originally planned with the intention ofattempting a Mediterranean climate at a location in Denmark. The main focus was on the possibility of greenery and the benefits of having a garden thatcould be used for recreation most of the year. At that point, the motivationwas not originally to make an energy-efficient building. The low energy consumption happened as a matter of secondary importance.Torkild Kristensen, a retired architect, designed and partly built the house himself.

Figure 1. TorkildKristensen'sdwelling seen from South East corner of greenhouse.

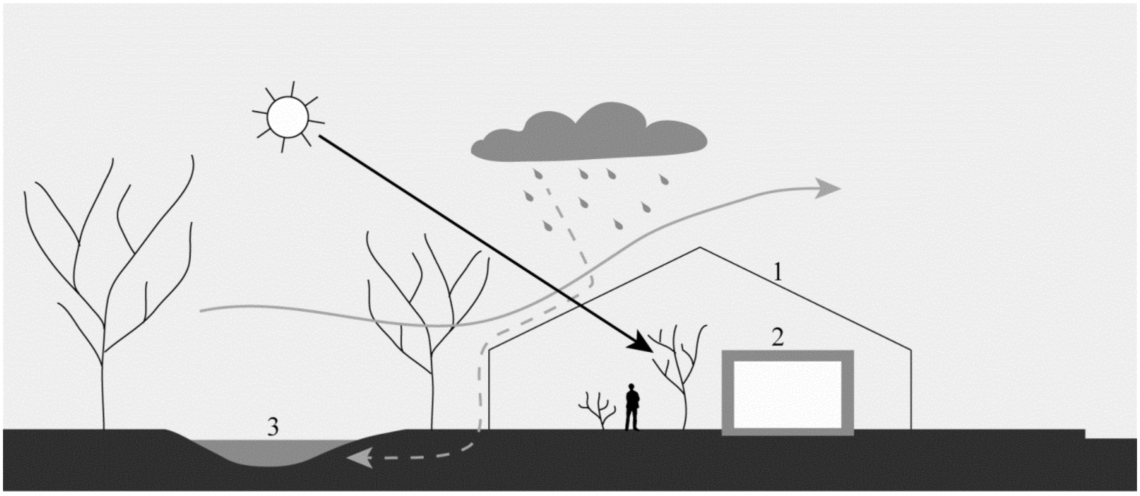

Figure 2.Concept of TorkildKristensen's house. 1: Standard industrial greenhouse. 2: Dwelling with light-weight plaster facades. 3: Pond for collecting rain water.

2.3 *Description*

The greenhouse is 400 square meters, measuring 16x24 meters with a height of 7 meters at the ridge. The dwelling inside is 62 square meters. The walls are built up as a light-weight construction of wood, plaster netting and 15mm of plaster. The insulation is 225mm of mineral wool. The windows are standard, double-glazed windows installed directly adjoining on the wall. The heating is floor heating supplied by district heating. The ground of the greenhouse is covered with standard bricks, leaving some openings of soil for greenery. Outside of the house there is a pond, which collects the rain that falls on the greenhouse and stores it for manual watering inside the greenhouse.

Torkild Kristensen´s househas a two-layered building envelope. The glass-skin protects from rain and wind, and the insulated inner walls assure a stable temperature inside the dwelling. This duality in the construction may be thought of as a windbreaker and a sweater (Fig. 2). The space between the two layers is used as a sheltered garden, where the wind-protection is highly valued by the inhabitant.The rain-protection is also significant, especially for the design advantages. The dwelling facades of plaster could never withstand direct rain or snow. The roofing and window details are less critical because rain and subsequent water infiltration are not a factor of concern. The dwelling's temperature keeps relatively stable, both in cold and overheated conditions of the greenhouse(Fig. 6).

The climate in the greenhouse can be regulated in different ways.All the glass of the greenhouse is overlapping, which gives a permanent gap for fresh air exchange.The windows by the ridge are mechanically adjusted, whereas the greenhouse's doors are manually controlled. When the doors and roof windows are simultaneously open, it creates a chimney-effect which is effective for air exchange. The manual adjustment of the doors has the drawback of being dependent of the presence of the inhabitant.

An internal curtain is located right beneath the glass roof. The curtain is partly transparent and partly reflective. It keeps the heat out during the warm months, whereas it insulates against the cold during the cold months.

To the south of the greenhouse there are deciduous trees, which provide optimal shading during the summer months, when the trees have leaves, and allow daylight to infiltrate the greenhouse during the winter months when the limbs are bare.According to Torkild Kristensen, the dwelling hardly uses any energy for heating and cooling. "The house can be heated with a single candle"(Kristensen 4th June 2013).This will be further researched.

The house is situated in the city of Odense, Denmark. Due to the building regulations it was a challenging process to get the local authorities approval of the project. Torkild Kristensen eventually got the permission to build on an industrial sitewhere there are not the same limitations of size as in standard residential areas.

The greenhouse had to be modified in order tomeet the requirements of the housing code by providing adequate fire exits and tempered glass in the roof.According to the inhabitant the dwelling inside the greenhouse had special permission to be built without a foundation and vapor barrier.

According to Torkild Kristensen, the economy of the project is the same as of a standard 120 square meter house. The missing foundation was one of the components, which caused cost reduction. The plaster used on the inside house was donated, as the manufacturer took an interest in the project. The greenhouse itself is a standard industrial product.

2.4 *The experienced varieties of the year cycle*

Torkild Kristensen:"The most significant is the fact that spring comes earlier and winter comes later. The summer and winter displaces at least three months - in favor of summer. Another thing is,when you just get pepped up like today. This can also be experienced at the 24th of December. The sun is just here for one hour, and then it becomes 20 degrees in here. That means, that if we just get a little light during the dark period, then you achieve the energy that summer and sun provides.

It is basically the light that is the key, because whether it is one or the other temperature outside is pretty irrelevant. The light gives the temperature in here. Besides, the lack of rain and wind means, that you have much more tendency of letting the doors open and things like that, because there is no draught." (Kristensen 30th September 2010).

Summer: "When we suffer under a heat wave and the temperature outside gets 30°c then I can keep the temperature in the greenhouse at 25°c because of the chimney effect."(Kristensen 4th June 2013).

Autumn: "The most exhausting thing is, when it is autumn without any light. I particularly remember one year, where the autumn was extra hard. I desire the daylight more than the temperature."(Kristensen 4th June 2013).

Winter: "Sometimes at winter I get these beautiful ice crystals on the glass of the greenhouse. And even if the sun is only there for one hour, then it is a very special time to have. The downside is that I sometimes forget to go outside."(Kristensen 4th June 2013).

Spring: "At Easter the greenhouse is in flower, and the activities in general are about one month ahead. The same goes with autumn. It is simply six months extended to nine months."(Kristensen 4th June 2013).

2.5 *The measured units*

Light iscrucial to thetemperature in the greenhouse. Light beams are converted into heat as they penetrate the glass. By comparing the measured temperature with registration of global radiation, it becomes evident that the temperature fluctuation is huge on a sunny day, whereas the temperature is more consistent and constant when it is overcast.

TorkildKristensen's statement about winter conditions, when the temperature can reach the level of summer, can be verified by a comparison of the data collected simultaneously on the inside of the greenhouse and the outside of the greenhouse (Fig. 3).

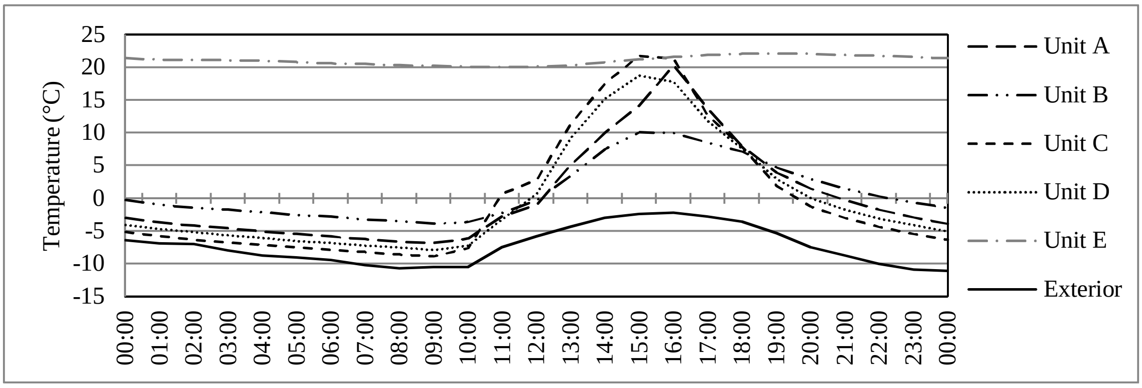

Figure 3. Example of 10th February 2012. Global Radiation is up to 381 MJ/m2.Unit A: South façade dwelling. Unit B: North facade dwelling. Unit C: South facade greenhouse. Unit D: Roof terrace. Unit E: Interior dwelling.

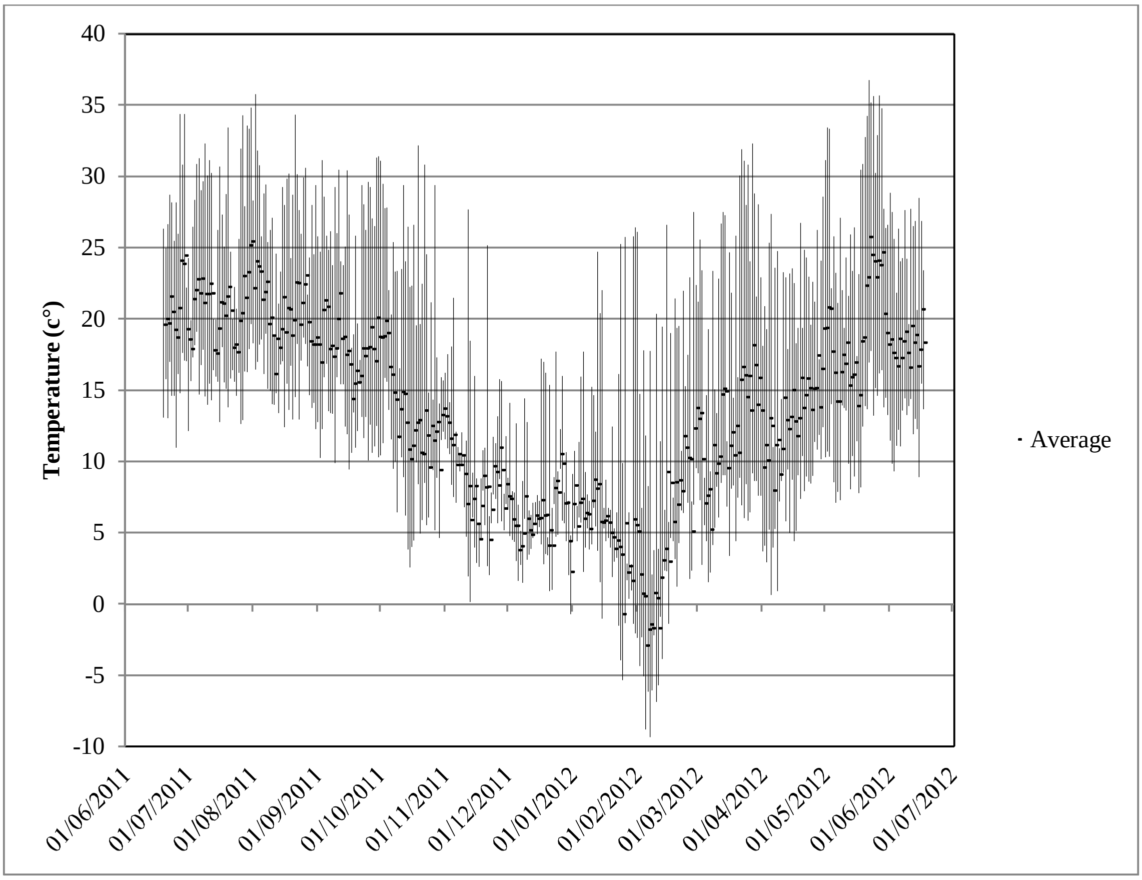

Figure 4. Measures of temperature in Greenhouse Unit A.The daily maximum, minimum and average of 24 hours throughout the total year of measuring.

Table 1. Length of the period with occurring frost during the year of measuring.

Place:	First frost:	Last frost:
Unit A	31-12-2011	16-02-2012
Unit B	23-01-2012	13-02-2012
Unit C	13-11-2011	08-04-2012
Unit D	13-11-2011	05-04-2012
Unit E	-	-
Exterior	13-11-2011	08-04-2012

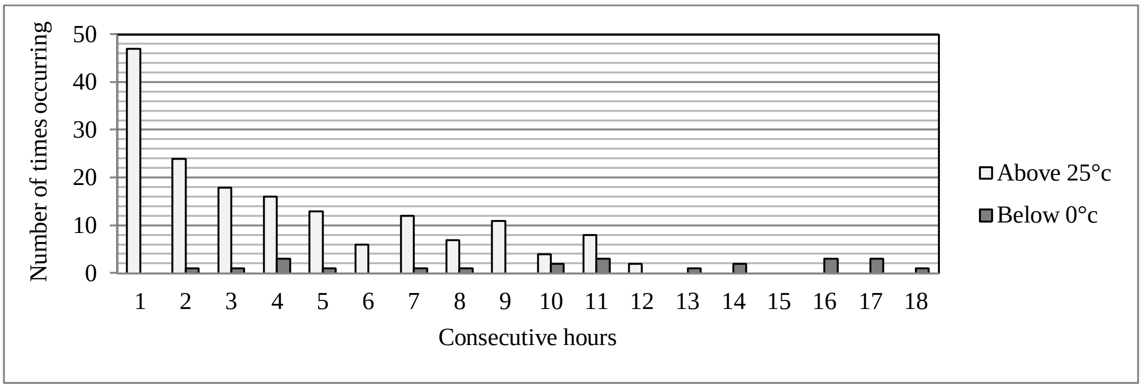

Figure 5. Measures of Greenhouse Unit A. Occurring number of times with consecutive hours.

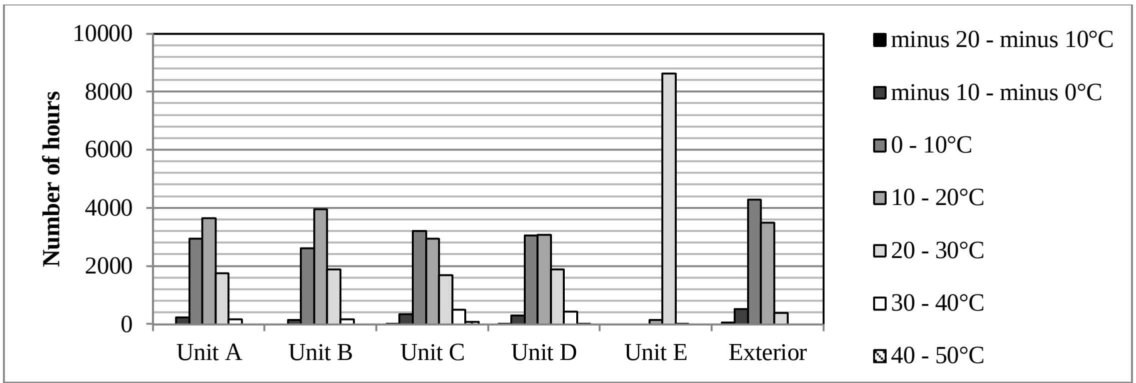

Figure 6. Measures of all Units and Exterior.Number of hours in temperature levels of 10°C.

The measurements inside the greenhouse show significant local differences in temperature. In general, the temperature of the house’s north side is more stable than on the south side. The north side of the house does not get as cold and as warm, as the rest of the house, whereas the temperatures at the roof terrace, Unit D, and by the south façade of greenhouse, Unit C, have severe fluctuation (Figs 3 and 6).The greenhouse offers a wider variation of temperature levels compared to the exterior (Fig. 6) The ongoing research will analyze if thediffering thermal qualities could be intentionally utilized in the design.

3 DISCUSSION

First of all, it is important to state that the greenhouse here is defined as outdoor space and the inside dwelling as indoor space. By this definition of the greenhouse as outdoor space it becomes evident, that it is not the intention to achieve a standard indoor environment of stable 21°c. It is the exact opposite. The original intention was to attempt a Mediterranean climate at a location in Denmark in order for benefit from the sunbeams in the protected garden during the cold months.

The typical skepticism about greenhouses concerns the risk of overheating and problems with humidity. The term “it is like living in a greenhouse” is often used as a negative term in relation to indoor climate. Geo Clausen,associate professor, Technical University of Denmark:“If you had asked me beforehand, I would have said that the idea of an inhabitable greenhouse is hopeless. I would have presumed that the temperature would be 60 degree Celsius" (Toftum & Clausen 14th June 2013). The result of the measured temperature shows that naturally there will be times, where the temperature is above 25 degree Celsius. However the measurements show that from May to October these periods last 1-3 days typically separated by a couple of days with lower temperatures. The temperature in these periods starts to fall in the early evening and continue falling during the night. The observations refer to the specific year of measurements.

During the measured year, there is a total number of 50 days, where the temperature at a particularly time of the day rises above 30 degrees in the greenhouse, Unit A. There is a maximum in occurrence in May 2012 where this happens for 10 consecutive days (Fig.4). The length of periods with temperature above 30 degrees is observed to last up to 7 consecutive hours per day.In these periods the indoor temperature typically lies 5-8 degrees Celsius lower than the temperature in the greenhouse. The measurements show variation in this pattern, which may be due to the absence of the inhabitant.

In general the temperature of the dwelling is relatively stable. The dwelling keeps warm during winter and relatively cold during summer probably due to the restricted use of openings in the facades. The dwelling thus serves as protection against the heat. The inhabitant expresses, that he can control the heat by opening the door in the greenhouse to the outside, let the wind in and due to the chimney effect push the heat out, so he reduces 30 gr. to a stabilized 25 gr. This cannot be verified by the measurements of the specific year, but the inhabitant has been away from the dwelling over long periods during the summer, which may be the reason. It will need further investigations.

Another critical question concerning the idea of living in a greenhouse is the supposition of humidity and related mold. The inhabitant claims that it has never been a problem, and the author has observed no proof to the contrary. On the rooftop and the roof terrace there are traces of humidity which, - according to the inhabitant, stems from the window in the ridge. The automatic closure mechanism is relatively slow and occasionally it does not close in due time for the rain. The average RH throughout the year of measuring is 83% in the exterior and 73% in Greenhouse Unit A – inside the dwelling it is 42%. According to the inhabitant, condensation hardly occurs because of the glass construction with open overlaps and the efficient chimney effect of the greenhouse. A conscious use of plants and trees with minimum water consumption may also have an effect.The author has not observed condensation, but her visits have primarily been mid-day in the warmer months, so the claim of limited condensation should be verified. The house has no mechanical ventilation from bathroom and kitchen. According to the inhabitant, it is not a problem because the greenhouse has a size with capacity to absorb the exhaust. However he mentions that the smell of cooking now and then hangs in the air. In general, it is important to underline, that the case study is only inhabited by one person. This means that the amount of humidity is relatively low compared to humidity produced by an average family. The large size of the greenhouse is estimated to supply the required fresh air exchange (Toftum & Clausen 14th June 2013). This big space offers an exceptional spatial experience to the inhabitant at the same time as it serves as it lowers energy consumption.

4 CONCLUSION

The research shows that Torkild Kristensen's house is a potential answer to the request of living "a good life" with a variety of sensual experiences in close connection with the seasons, greenery and the elements of nature. It is a building type that offers a stimulating setting in combination with diminishing energy consumption. In Table 2 it can be seen that the difference in monthly maximum temperature between Coimbra in Portugal and the Greenhouse Unit A varies up to +/-5 degrees Celsius. In comparison, the difference in monthly maximum temperature between Odense in Denmark and Greenhouse Unit A varies up to +18 degrees Celsius – in favor of the greenhouse.Table 2 represents monthly average of daily maximum temperatures.

Table 2.Comparison of the climate in Denmark, Portugal and Greenhouse, Unit A. The table is based on the average of daily maximum temperature throughout the month and the average of minimum temperature throughout the month. Relative humidity (RH%) is based on a monthly average.(DanmarksMeteorologiskeInstitut 2001)Climatological data based on averages of a 30-years period).

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Denmark. Odense (30 years):												
Max.temperature (C°)	2	2	5	11	16	20	21	21	18	12	7	4
Min.temperature (C°)	-2	-3	-1	2	6	9	11	12	9	5	3	0
RH (%)	87	84	78	70	64	65	67	69	73	79	86	89
Portugal. Coimbra (30 years):												
Max.temperature (C°)	14	16	18	21	23	26	29	29	27	23	18	14
Min.temperature (C°)	5	6	8	9	11	14	15	15	14	12	9	6
RH (%)	66	58	59	52	55	52	46	45	49	55	64	69
Greenhouse - Unit A: (1 year)												
Max.temperature (C°)	13	15	23	21	28	26	28	28	26	23	13	10
Min.temperature (C°)	2	0	7	7	12	13	16	16	13	9	6	4
RH (%)	83	71	68	62	59	64	71	73	73	78	88	88

Torkild Kristensen expresses great joy of having the opportunity to stay in his garden for an extended part of the year. The greenhouse itself becomes a motivator that generates a more active life, which together with the increased exposure to daylight are an advantage to health and well-being in general. It is necessary for the inhabitants to actively regulate the climate and adjust by modifying their clothing.The inhabitant needs to have a positive perception of the shifting conditions and appreciate the special qualities it brings. Behavior is crucial - in that sense this concept of living is not a universal design, which fits any given inhabitant.

Torkild Kristensen´s house was designed primarily to achieve a higher quality of living - saving of energy happened as a matter of secondary importance. This backward approach has resulted in a house, where the energy saving installation itself becomes valuable to the architecture. Architects are trying to minimize the aesthetic disadvantages of sustainable installations such as solar cells, low-energy windows etc. These installations attempt to be integrated into the architecture or made invisible without any further contribution to the architecture and spatial quality. The inhabitable greenhouse is opposite. The greenhouse works as an energy saver, but it also adds a large useful space with varying stimuli, sensual experiences and recreational sunlit space. This reversed approach could potentially form the basis of further development.

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Criteria for thermal rehabilitation of hotels in Gran Canaria

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ABSTRACT: The mass tourism led mainly to two consequences on Gran Canaria. On the positive hand, it has become the economic driving force of the territory. On the negative hand, it has involved irreversible landscape degradation. The current strategies in the island is to achieve a tourist model of higher quality focus on sustainability criteria starting from the renovation of the existing tourist accommodation establishments.
The aim of the research is to establish criteria for the rehabilitation of the envelope of hotels in Gran Canaria in order to minimize the environmental impact due to the use. Two scenarios arise, conservation and maintenance of the current envelope and adaptation to the current existing technical regulations, the Technical Building Code (CTE). CTE, being an instrument of Spanish Government's commitments under the framework of the Kyoto Protocol on the environment, has higher demands on thermal requirements of the buildings envelope than in previous regulations.

1 JUSTIFICATION AND IDENTIFICATION OF THE PROBLEMS

1.1 *Introduction*

In the Canary Islands, the tourist industry generates 83% of the regional Gross Domestic Product (ISTAC 2009). We must take into account that, apart from being the lifeblood of the region, the tourist industry requires a high energy consumption derived from the accommodation and associated services.

In the hotel construction on Gran Canaria before 2000, the thermal quality of the envelope has not been taken into consideration in order to ensure an appropriate internal thermal comfort, satisfying, in this way, the non-existent or reduced needs of mechanical air-conditioning which involve a low energy consumption throughout the whole useful life of the building. It is due to the mild climate conditions of the island as well as the fact that, on the Canary Islands, it was not compulsory to limit the global heat transmission through building enclosure, according to the technical regulations in force at that moment.

With the arrival of the Código Técnico de la Edificación (The Spanish Technical Building Code; hereafter the CTE) in 2006, one of the objectives of which is the improvement of the building quality and which represents a means of long-range commitments of the Spanish Government as regards the environment, higher requirements arise regarding the thermal factor and energy consumption. In this case, the Canary Islands are not exempt of its observance.

In addition, the tourist areas on Gran Canaria are in the process of renovation of the existing tourist accommodation establishments following the current strategies of the sector aimed at a proper sustainable development. It is evident that any alternations in the envelope of a building after the approval of the CTE must comply with the requirements demanded by the regulation, irrespective of whether the intended effects of the energy saving are achieved, since the climate conditions of the Canary Islands question this objective.

1.2 *Geoclimatic singularities of Gran Canaria*

Gran Canaria, which is located at a latitude of 28ºN, is in the warm zone. Its climate is conditioned by numerous factors, such as the geographical latitude, the orography and the orientation, the sea and the proximity to the African continent. Due to the subtropical character of the Island, the weather is spring-like throughout the whole year, that is to say, mild and without hardly seasonal contrasts. However, in spite of the climate excellence, which makes possible that all coastal locations of Gran Canaria are in the tourist season throughout the whole year, the relief of the Island produces climatic contrasts between the north area and the south area of the Island (Hernández 1979; Nadal and Guitián 1983; Franco 2004).

The orography, characterized by a slope of around 10-20% from the central summit to the sea, represents an obstacle and a barrier to the direction of the trade winds originated in the anticyclone of the Azores Islands, which leads to an unequal distribution of temperature and humidity between the north-facing slope, windward, and the south-facing slope, leeward. Therefore, the north-facing slope is wetter, without hardly thermal fluctuations and with a sea of clouds that settles over the capital town, principally in the summer months; while the south-facing slope remains cloudless, dry and with higher temperatures (ITC 2007).

1.3 *Normative evolution*

It is a fact that laws and regulations develop as a result of the evolution of the society. In this way, the evolution experienced by the society, from the individual concern to the global awareness, is also undergone by legislation. So, in Spain, with the arrival of the Spanish Technical Building Code in 2006 (CTE), the aspect of sustainability is added to the safety and quality of the construction, aspects that were taken into consideration in the previous regulations.

Therefore, the energy consumption of buildings in Spain has been regulated throughout the time by three regulations: the Decree1490/1975, which lays down measures which must be observed in the construction, in order to reduce the energy consumption; the Royal Decree 2429/1979, which establishes the basic regulation of the construction of thermal conditions in buildings, and currently the CTE, in particular, in the Basic Document of Energy Saving "DB HE: Ahorro de Energía". This evolution of technical regulations has affected the forms of calculation as well as the values which must be observed, which are generally more and more restrictive.

It should be pointed out that the Canary Islands, due to their special climatic conditions, were exempt from complying with the global thermal transmission coefficient of the previous regulations. This led to a construction in this region without taking into consideration the thermal isolation, which resulted, in spite of the mild weather, in an energy consumption due to a disproportionate use (Nicolás et al. 2011). Nowadays, in order to comply with the requirements stipulated in the CTE for the Canary Islands, it has been necessary to modify the structural systems commonly used so far in the envelope of buildings, increasing principally its isolating capacity.

2 OBJECTIVES

Taking into account the importance of the tourist industry on Gran Canaria, it is very important to know if the adaptation of the envelope of its hotels to the current regulation (CTE) involves environmental benefits from the thermal point of view, ensuring the internal comfort for users.

So it will be possible to establish criteria for the thermal rehabilitation adapted to the warm climate of Gran Canaria, which is very different from the climate of the rest of Spain. Therefore, the objective of this study is the analysis of the application of the CTE in coastal areas with annual climate conditions which do not require air-conditioning demand.

3 METHODOLOGY

The context of the research is the tourist architecture on Gran Canaria in the 20th century. A representative model, the typical hotel and the typical room, is obtained from the analysis of the existing 4 and 5 stars hotels on Gran Canaria built before 2000, a total of 34 hotels.

The designed model is used to do all necessary calculations and studies for the quantification of the air-conditioning demand in two specific locations, which are places of tourist concentration and with different microclimates on the same island: Las Palmas de Gran Canaria (hereafter LPGC) and San Bartolomé de Tirajana (hereafter SBDT), located in the north and south, respectively.

The typical room is the analysis unit and results are extrapolated from it to obtain the ones of the typical hotel. So, the results of the typical hotel are the sum of the corresponding results of a certain number of typical rooms, defined depending on their orientation and location, without taking into consideration the common areas and de operation of the hotel.

The air-conditioning demand, corresponding to the optimal level of internal thermal comfort of an average user against the external climatic conditions and the characteristics of the envelope, is calculated from the annual average thermal calculation. To obtain this balance, it is necessary to calculate the corresponding values of the parameters of the external environment of the envelope and of the internal environment. The external environment is defined by the average temperatures and the solar incidence rate and emittance; the envelope by its physical parameters and orientation, and the internal environment by the comfort temperatures throughout the whole year, depending on the metabolic and clothing characteristics of an average user.

The annual average thermal calculation of the typical room is calculated taking a representative day of each month of the year, for all possible orientations in both pre-established locations (LPGC and SBDT), and combining the different alternatives of envelope proposed in this thesis (conservation and maintenance of the current envelope and adaptation to the CTE of the current envelope), the orientation and the location of the typical room in the building of the typical hotel (typical floor or top floor, standard room or in a corner).

The annual average thermal calculation of the typical hotel is calculated from the addition of its typical rooms. Due to the difference of the results obtained for the different typical rooms, depending on their location in the hotel (in a typical floor or in top floor, in a corner or between rooms), it is considered appropriate to study variations of the typical hotel as well. These variations will have the same number of rooms, but distributed in different heights: 2 floors, 12 floors and 20 floors.

Finally, with the 104 study cases of typical rooms studied, 48 study cases of typical hotels are obtained with all possible combinations: 12 hotels x 2 locations x 2 envelopes.

The calculation to obtain the annual average thermal calculation is based in the method of estimation of the daily thermal load, developed by the Doctor of Architecture Manuel Martín Monroy (2006) which, thanks to a simplified data entry and an interactive results output, facilitates the study and evaluation of alternatives.

3.1 *The typical hotel*

The typical hotel, obtained from the fieldwork, does not have a specific location. It can be located in any tourist place of the coastal area of LPGC or SBDT.

Regardless of the coastal area where the hotel is located, it has a 4 stars category and it is considered to be 25 years old in 2010.

The building is exempt from limits of the plot and is surrounded by the gardens and swimming-pools of the common areas. It is rectangular in shape, respecting the perpendicularity between the adjacent façades and the parallelism between the opposite ones, and its dimensions are defined from its rooms and their distribution in the building.

It has a height of 9 floors, i.e. 1 ground floor, 7 typical floors and 1 top floor. The ground floor of the hotel is used for the public and administrative areas (hall, reception, lobby, living rooms, restaurant, dining room…) and the typical floors and the top floor for the private area (rooms).

The total number of rooms is 240 and all of them are considered double rooms with balcony. They are distributed in the 7 typical floors and the top floor, so each floor has 30 rooms. They are arranged on both sides of a central corridor of distribution, so 4 rooms are in a corner and 26 are standard rooms.

The typical hotel does not have a specific orientation. It can be located in any direction according to the cardinal points and their bisectrix. As a result, as it can be observed in Figure 1, there are four possible orientations: E-W, N-S, NE-SW y NW-SE. In values of solar intensity, in the orientations NE-SW and NW-SE there is symmetry with respect to the south and, in consequence, results will be equal.

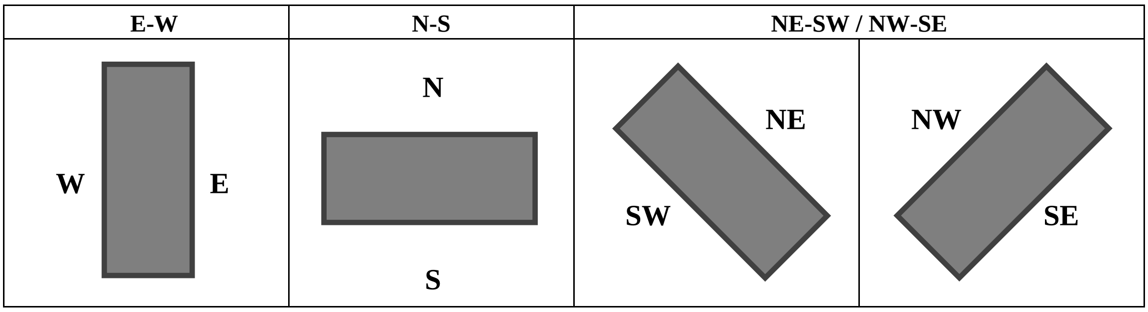

Figure 1. Typical hotel orientations within the plot

Therefore, the envelope of the typical hotel consists of two main façades, two side façades and a flat roof. Individual terraces and doors-opening are in the main façades, with a proportion lower than 60% with respect to the whole enclosure in the same plane. The side façades and the roof do not have any compositional elements, windows opening or skylights.

The opaque enclosure of the main and side façades, so-called façade wall, is made of concrete hollow blocks with a continuous external covering of mortar rendering and light color superficial paint and an internal covering of plastering and plaster coating. It has aluminium frames and single strength window glass of 8-mm colourless glass. The roof is traditional, non accessible and with a finish of clay tile surface.

4 RESULTS

From the annual average thermal calculation of typical rooms, it is calculated the air conditioning demand of the typical hotel for the two locations (LPGC and SBDT), in all orientations it can have (W-E, N-S and NE-SW/NW-SE) and with the two types of building envelope: conservation and maintenance of the current envelope and adaptation to the CTE of it.

Due to the difference results of air conditioning demand between different typical rooms is convenient to study the impact of the air conditioning demand in typical hotel with various numbers of floors as well. Therefore, keeping the same number of rooms in the typical hotel (240 rooms), is also calculated for a typical hotel with 2, 12 and 20 floors.

Results of the air conditioning demand for each of the variants of the typical hotel according to the number of floors are plotted in Figures 2–5.

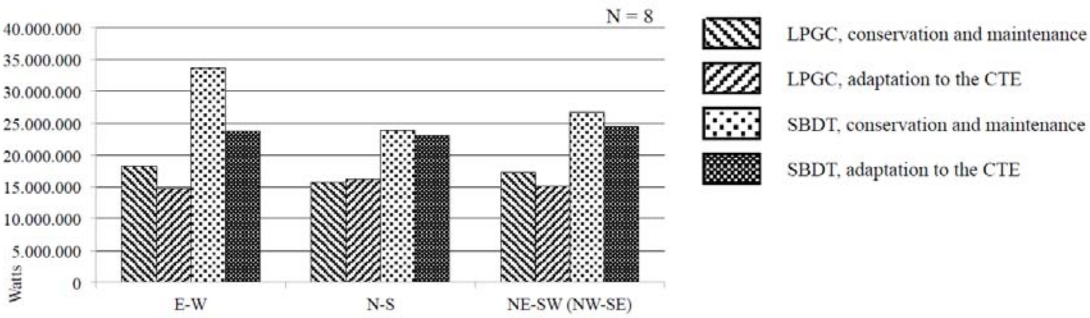

Figure 2. Air conditioning demand of the typical hotel

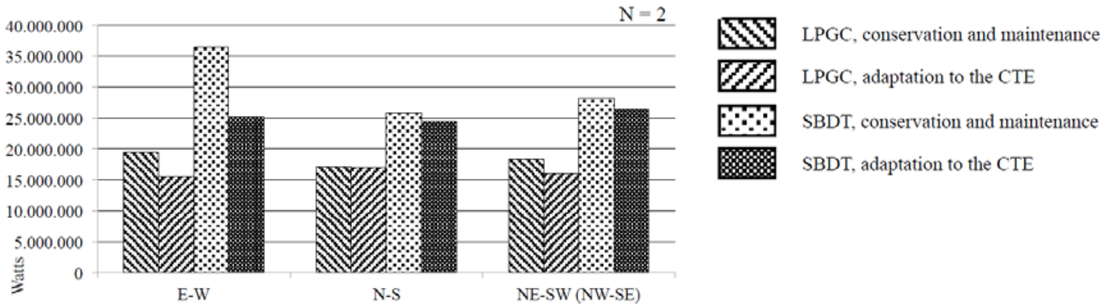

Figure 3. Air conditioning demand of the two-floors typical hotel

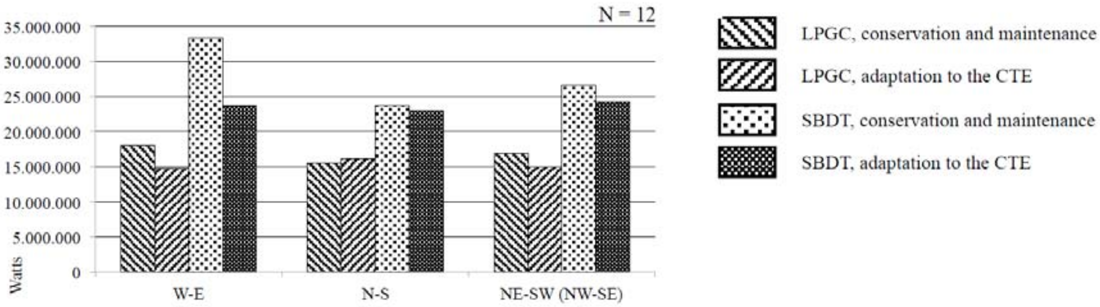

Figure 4. Air conditioning demand of the twelve-floors typical hotel

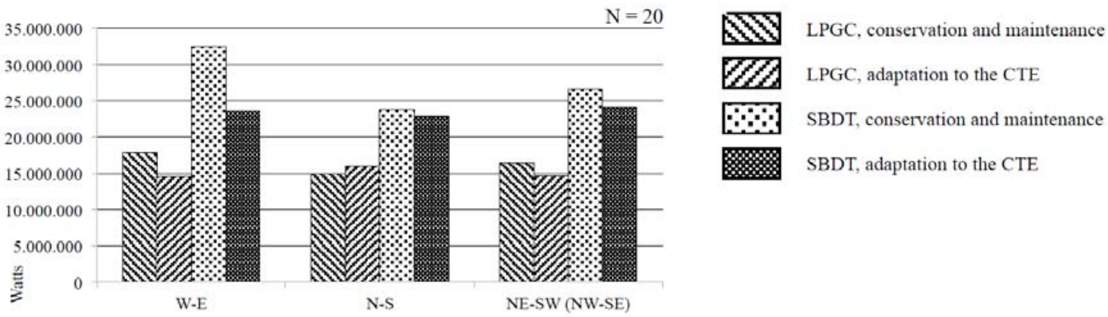

Figure 5. Air conditioning demand of the twenty-floors typical hotel

4.1 *Annual air conditioning demand depending on number of floors*

Number of floors have directly influence in final demand outcomes, so if the number of floors in the typical hotel decreases, the air conditioning demand increases. Comparing the variants of typical hotel with 20 and 2 floors, the demand reduction is more pronounced in E-W orientation in SBDT and in N-S in LPGC, with 12%-15% for conservation and maintenance of the current envelope and 6%-7% for adaptation of the current envelope to the CTE.

Although the numerical values vary, the behavior of the results can be considered similar in all cases. That is why in following analysis we will refer only to typical hotel with 8 floors.

4.2 *Annual air conditioning demand depending on location*

The air conditioning demand of the typical hotel is higher in SBDT than in LPGC. The increases range from 42% in the N-S orientation with conservation and maintenance of the current envelope to 85% in the E-W orientation with adaptation it to the CTE.

Both locations, in orientations E-W and NE-SW/NW-SE, behave similarly despite of the numerical difference in results. That is, the more favorable options in LPGC are also the most favorable in SBDT. In the orientation N-S, the opposite occurs.

4.3 *Annual air conditioning demand depending on orientation*

In conservation and maintenance of the current envelope, in both locations, LPGC and SBDT, greater demands are produced in the orientation E-W. However, lower demands are corresponding to N-S.

If the adaptation to the CTE of the current envelope takes place, there are differences depending on location. The highest demand corresponds to the orientation N-S in LPGC and NE-SW/NW-SE in SBDT, and the lowest demand to E-W in LPGC and N-S in SBDT.

4.4 *Annual air conditioning demand depending on building envelope*

The adaptation to the CTE represents a marked decrease in the demand in the orientation E-W, where it produces the greatest savings over conservation and maintenance of the current envelope with 18% in LPGC and 30% in SBDT.

In the orientation NE-SW/NW-SE the demand is also reduced with the adaptation to the CTE of the current envelope. But, unlike the previous case, the largest savings are producing in LPGC, with 12%. SBDT only reaches the 8%.

In the orientation N-S the results with different envelope buildings type represent a saving of 3% in favour of the conservation and maintenance of the current envelope in LPGC (it is the only case) and in favour of the adaptation to the CTE in SBDT.

5 CONCLUSIONS

From this study of the air conditioning demand in the typical hotel is proved that:

1. Due to the mild climate of Gran Canaria, in the coastal area there is no demand for heating in winter. The air conditioning to keep the typical hotel within the comfort area inside corresponds only with cooling demand during the summer months mainly, although in some cases the interval can range from late spring until the beginning of autumn. The remaining months of the year, the typical hotel can support by natural renewal to optimize the thermal performance and avoid the need for mechanical equipment in order to establish an internal temperature of comfort.

2. The reduction in the demand for cooling sought by the CTE depends on the specific climatic conditions of the location of the typical hotel. Under the provisions of CTE for the study areas, the adaptation of the current envelope in the typical hotel involves a considerable reduction of the thermal transmittance in building enclosures (U) and modified solar factor in semi-transparent surfaces (F). Therefore, the adaptation to the CTE should produce a decrease in the demand for cooling. This assumption is fulfilled in the location of SBDT but not in all cases of LPGC. The explanation comes from the fact that, in the mild climate of the Gran Canaria, SBDT has more extreme weather conditions than LPGC, although the CTE assigns them the same climatic zone (A3).

3. The resulting values of the air conditioning demand in the typical hotel when it has its current envelope adapted to the CTE are almost similar in all orientations. In this option the differences of results amongst different orientations (E-W, N-S, NE-SW/NW-SE) are around 6%, unlike keeping the current envelope without the adaptation to the CTE where these reach the 15%. The CTE by establishing only limit guidelines for modified solar factor in orientations E-W and SE-SW has restricted heat gains in orientations more punished by solar incidence. It produces a greater homogenization of the results of air conditioning demand, which means that if the envelope is adapted to the CTE, the orientation of the typical hotel is not a relevant factor for obtaining a lower air conditioning demand.

4. If the adaptation to the CTE of the current envelope of the typical hotel takes place, applying the decrease of solar factor in semitransparent surfaces (F) is more effective in the demand for cooling than the decrease of thermal transmittance in any of the building envelope elements (U). This is because semitransparent surfaces are more vulnerable than façade walls to solar effects which have directly influence in the demand for cooling, and the thermal transmittance focuses more to limit heat loss and improve the demand for heating. At the main façade of the typical hotel the semitransparent surfaces and the opaque enclosures have similar proportions.

Adding the particular climatic conditions of Gran Canaria, it is of great interest to act on modified solar factor in all orientations to limit the maximum of solar radiation at normal incidence that can pass through it. However, the CTE for the climate zone corresponding to LPGC and SBDT (A3) only lays down the requirements of modified solar factor in orientations E/W and SE/SW with spaces with low internal loads and over 40% of semitransparent surfaces.

5. The percentage of shade in Gran Canaria established by the CTE must be obtained by simulation. The values set for the shading factor (FS) in tables E.11-E.15 of HE1 of the CTE should no be used for Canary Islands due to the 12 difference degree in latitude existing with the rest of Spain. In addition, these tables do not differentiate between seasons. This is because in the CTE the existence of elements that can generate shadow is directly related to the modified solar factor and, therefore, more intended to limit heat gain in the summer months. In Gran Canaria, its particular climatic conditions make that the benefit of shadow elements in the air conditioning demand should be considered throughout the year.

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Optimization of the Sustainability during the Refurbishment Operation of a Residential Building

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ABSTRACT: Most of the existing buildings have high resources consumption and low indoor environmental quality, leading to the unsustainability of the built environment.
Being aware of this reality and based in the European goal to achieve Nearly-Zero Energy consumption standard in buildings, it is urgent to define guidelines that could support the sustainable refurbishment design since the earlier stages.
This paper intends to illustrate the process of sustainable building refurbishment, supported by different guidelines applied to a case study. To achieve this goal the definition and evaluation of a group of procedures to be implemented, and a cost-benefit analysis applied to a case study was performed, having as final goal its sustainability optimization.

1. INTRODUCTION

1.1 *General introduction*

The refurbishment of the built heritage proved to be the way to achieve sustainability in the urbanity and construction fields, because it preserves the cultural values, the environment and it has severaleconomic advantages.

In Portugal there are several programs that were developed to supportthe refurbishment of buildings, such as REHABITA, RECRIA, RECRIPH, SOLARH and JESSICA, that give incentives through tax benefits.

However, it is necessary that refurbishment is performed according to the sustainability guidelines. The first steps in Portugal towards sustainability were given with the introduction of the RCCTE (regulation for building thermal characteristics). Some guides were also developed related to the thermal refurbishment, but it is necessary to go beyond.Optimizing the buildings in the several strands, such as energy and water consumption, functional adequacy, sufficient natural lighting, good proportion of the interior spaces, preserve the existing materials and use more sustainable materials.

The study object of this paper is the residential buildings located in the Historic Centers. It pretends to analyze the complexity of the architectonic project, of its use and maintenance, to optimize the building sustainability.

1.2 *Aims*

The main goal of this work is to define the best sustainable practices to be applied in the refurbishment of a residential building with cultural value. It is intended to define constructive and spatial solutions, allied to renewable energy, that optimize the sustainability of the residential building, such as:

- Optimize the sunlight (e.g. solar panels);
- Optimize the efficiency of water resources (e.g. collect the rainwater, re-use of the gray water, and to implement systems that minimize the use of water);
- Maximize the preservation and re-use of existing materials;
- Minimize the production of waste;
- Maximize the use of sustainable materials, with low incorporate energy, recycled and recyclable;
- Optimize the thermal comfort conditions (e.g. implement insulation in the exterior walls, efficient acclimatization systems, and insulation of the windows);
- Maximize the natural ventilation;
- Implement shading systems,
- Make a cost-benefit analysis of the previous mentioned approaches.

These solutions will be developed in the refurbishment of a residential building located in the Historic Center of Braga.

As a work method will be adopted methodologies for sustainability assessment, to define and implement the solutions that prove to be more sustainable, analyzing the environmental impact till the cost-benefits of the solutions. It will be use the Thermal Simulation Assessment Tool (Ecotect), the Constructive Evaluation Assessment Tool(SimaPro- Mars-SCMethodologie) and the Sustainability Assessment Tool (Sbtool^{PT}) as the evaluation of the final performance of the building.

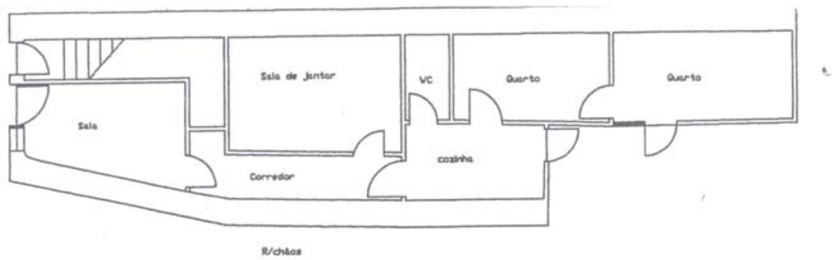
2. CASE STUDY

2.1 *BuildingPresentation*

The residential building (Figure 1),believed to be of the XVIII Century, is located in Braga, morespecifically in the Rua da Boavista, that is integrated in the Urban Critical Area of Recovery and Redevelopment of Braga. The building is divided in three floors, ground-floor, first floor and second floor, and subdivided in three different independent housing (one per floor).

The main entrances are located at the level of the ground floor, there is one that serves the ground floor housing and the other that serves the other independent housing that have a common stair case. The lot has a total area of 180,00 m^2, the exterior area has 111,20 m^2 and the building has a total area of 192,60 m^2. The building is oriented South-North, being the main façade oriented south.

The exterior walls are in stone masonry, plastered and painted white, the pavements are in wood supported by a wood structure, with the exception of the ground floor that is covered in parquet on a cement structure. The interior walls are built in a wood structure and plaster covered with vertical pieces of wood. The windows have a wood frame with simple glass, protect by exterior blinds or with interior iron shutters.


A


B

Figure 1 – (A) Picture of the front façade of the house; (B) Ground Floor plan of the existing

2.2 *Intervention Proposal*

The intention of the architectural project is to convert the three independent housing in two, being the first housing (housing I) composed by the ground and first floors and the second housing (housing II) by the second and last floor. It is intended to reorganize the interior spaces in order to capture natural light and have natural ventilation in all of them. Since the existing interior spaces are very narrow and some bedrooms don't even have direct natural light. It will also be implemented a skylight, some new windows will be open and in some situations, will have larger dimensions. The skylight will be located over the stair that connects the ground and first floors, and will have some side adjustable air vents, to ventilate the interior spaces. This solution can have a lot of internal gains in the summer period, and losses during the winter, so the skylight will be built in a thermal frame with double glass, and tight adjustable air vents.

The exterior space of the lot was also intervened in order to better capture the natural light into the interior spaces of the building, for that the levels of the terrain were altered, and a garage with green roof was implemented.

3. ASSESSMENT METHODOLOGIES

3.1 *SustainableImpact Assessment Tool of Constructive Solutions*

The assessment of the environmental impact will be realized with the computer program SimaPro 7.3.

This program is a methodology of Life Cycle Assessment (LCA) that evaluates the environmental impacts of the industrial products, and comprehends an analysis since the raw material extraction till it final disposal.

The SimaPro uses the method CML2 baseline 2000 that allows an evaluation of different constructive solutions represented by ten indicators that are distributed in ten categories, from which were chosen for this study, ADP (potential reduction of the non-renewable resources); AP (acidification potential); GWP (global warming potential); ODP (Ozone destruction potential); PODP (tropospheric ozone destruction potential); EP (eutrophication potential).

The data collected from the SimaPro program will be important for the evaluation of the constructive solutions, where will be used the MARS-SC methodology to assess the sustainability of the constructive solutions (Bragança, Mateus, 2006).

This methodology intends to clarify which constructive solutions are more sustainable, and evaluates the performance of the constructive solutions in three dimensions, environmental (IA), functional (IF) and economic (IE). The intention is to improve the existing constructive solution of the building by evaluating which solutions are more sustainable to do it.

MARS-SC methodology is developed in four steps, such as Quantification of the parameters;Normalization of the parameters;Aggregation of the parameters;Definition of the sustainable level (NS).

The normalization of the parameters is calculated by the equation Diaz-Balteiro (2004), Equation 1:

$$\bar{P}_i=(P_i-P^*_i)/(P_i^{**}-P^*_i)\ \square I \qquad (1)$$

Pi= quantification of the solution parameter; P*i= worst value; Pi**= best value.

The evaluation is limited in a scale from 0 (worst) till 1 (best) (Bragança, Mateus, 2006).

To aggregate the parameters is calculated the partial performance of each solution by each indicator (Ii), which is calculated by the respective equations (Bragança, Mateus, 2006):

$$\text{Environmental Performance: } IA = \Sigma W_{Ai}.\bar{P}_{Ai} \qquad (2)$$

$$\text{Functional Performance: } IF = \Sigma W_{Fi}.\bar{P}_{Fi} \qquad (3)$$

$$\text{Economic Performance: } IE = \bar{P}_E \qquad (4)$$

After calculating each parameter for each solution, we are able to calculate the sustainable score (NS) by the equation (Bragança, Mateus, 2006):

$$NS = WG1.IA + WG2.IF + WG3.IE \quad (5)$$

Wi= weight of each parameter; Ns= Sustainable Score, that comprehends the values between 0 (worst) and 1 (best).

The definition and quantification is made according to the objective of the evaluation, in the present work was attempted to find an equilibrium between what is intended and the indicators for which could be possible to find more information (Table 1). Since many manufacturers don't have available data for their products for the several indicators.

The weight that was given to each parameter is based in the study that is intended, normally the weight by defect for each indicator are distributed in the following way, for Environmental (0,40), for Functional (0,40) and for Economic (0,20). Here it was given a bigger weight to the functional component because it has a more direct impact in the comfort of the users,in consequence of the location of the building, that has not much direct light entering into the interior spaces.

Table1 – Weight of the parameters and of the indicators in each parameter.

	Dimensions					
	Environmental		Functional		Economic	
Indicators	Global Warming Potencial (PAG)	0,25	Sound Insulation to the Air Conduction (DnT,w)	0,3(3)	Construction Cost	1,00
	PrimaryEnergyEmbodied(PEC)	0,75	Thickness(Walls) orInsulation of the air percussion Sounds (L' n,w) (pavements)	0,3(3)		
			Termal Insulation (Umed)	0,3(3)		
	0,30		0,50		0,20	

3.2*Thermal Simulation Assessment Tool*

With the simulation of thermal comfort is intended to analyze the building in energetic performance terms, applying the constructive solutions that were analyzed.

The Ecotectas a flexible and easily apprehended software is a 3D simulation system that consists in a range of simulations and thermal analysis, with the goal to improve the energetic performance of the existing and new buildings. In the present work, although the program offers a different possibility of analysis, it will be focused on the thermal performance analysis, calculating the needs of heating, cooling and analyzing the occupation standards, internal gains, infiltration and equipment (Table 2).

Table 2 –Building use conditions

Use Conditions	Housing I
Nº of Persons (P)	6
Ocupation /Use Conditions	20h00 – 08h00 = 6 P 09h00 – 19h00 = 3P(70 W/ P – sedentary)
Clothes (clo)	1,0
Lightningandequipment	Sensible gains = 5 W/ m^2- Latent gains = 2 W/ m^2
Comfort Temperature	18ºC - 25ºC
Interior Humidity (%)	60,0
Air speed	0,50 m/s – Soft breeze
Ventilation	Mix mode – Heating/Cooling - Eficiency = COP 4
AirInfiltration	0,50 exchang/ hr (wellinsulated)

3.3 *Sustainable Assessment Tool*

The assessment of the sustainability of the residential building will be held using the system SBTool^{pt}, which allows the assessment and certification ofthe sustainability of a building (iiSBE, 2011). The evaluation includes not only environmental aspects but also social and economic.

This assessment tool will allow, in the case study, to evaluate the sustainability of the building optimization, in order to verify if all the measures that were implemented will contribute to have a good sustainable score.

The values obtained in each parameter are normalized and converted to a scale from 0 (reference value) to 1 (best value), that are translate in a scale from E (worst) to A+ (Best).

4. EVALUATION AND OPTIMIZATION OF THE SUSTAINABILITY

4.1 *Construction solutions*

The construction solutions that were chosen for the building envelop were different for the front and back facades, due to the street alignments of the front façade. The rehabilitation of the front façade was done on the interior and the back facades were done on the exterior. Different constructive solutions were also taken in consideration for the interior walls and pavements.

Analyzing the different constructive solutions through the Environmental impact assessment tool, it was defined which solutionswere going to be implemented for the front Façade walls, for the back Façade walls, for the interior walls and for the pavements.

4.2 *Systems to be implemented*

4.2.1 *Passive Solar Systems*

To improve passive systems, there were chosen some architectonic measures to be implemented such as, the reorganization of the interior spaces, the introduction of a skylight, new and bigger windows, in order to promote natural ventilation and capture more natural light to the interior spaces. The thermal insulation was improved not only in the walls and roof, but also in the window frames.

4.2.2 *Active Systems*

Apart from the passive systems, there were implemented some active systems. For heating, cooling and hot water of the housing (I), it was chosen a Heat pump connected to a solar panel, and for the housing (II), it was chosen for heating and hot water a Heat recovery system that is also connected to a solar panel. To complement both systems, it will be implemented a system of ventilation with tubs embodied in the soil, functioning as heat recovery system, this allows the new air that enters into the houses to be, during the winter, more warm and in the summer more cold.

A system of collection and treatment of rain and bath water will also be implemented. This water will be used for sanitary discharges, irrigation and pavement cleaning. In a very summary analysis, the implementation of this system with flow controllers will reduce the use of drinking water in about 50%.

To reduce the costs with electricity, all the artificial illumination will be in LED bulbs, and all the electric equipment’s will be the most efficient as possible.

A system of photovoltaic panels was thought to be implemented, but due to the location, orientation and surroundings of the building it wouldn’t be viable it implementation.

4.3*Thermal Assessment of the Building*

Through the thermal evaluation of the building (Ecotect), it was verified that the housing (I), with the systems that were thought to be implemented, had an annual consumption of 7,75 kWh/m^2 and the housing (II) an annual consumption of 30,4 kWh/m^2. The consumption are higher for the housing (II) than for the housing (I), though the housing (I) has more area, because the systems that were implemented in the housing (I) are more efficient (COP 4), which leads to lower annual consumption.

4.4*Sustainability Assessment of the Building*

For the evaluation of the sustainability it were used the spreadsheets of the SBTool^{pt} methodology. In the analysis were obtain the following values for each parameter in the different categories and in the differentDimensions (Table 3 and Table 4).

The values of each Dimension were normalized and it was obtained the Final Sustainable Score of 0,98 which represents the letter A (Table 5).

Table 3 – Values for the Environmental Dimension

Category	Parameters (PID)	Performance	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
C1 – Climatic changes and air quality	P1 - Aggregated value of the life cycle environmental impact categories of the building for m2 of useful pavement area per year	B	0,548	12	0,066
C2 – Use of soil and biodiversity	P2 - Percentage of usage of the liquid indicator available	A+	1,080	19	0,205
	P3 - Impermeabilization index	C			
	P4 - Percentage of intervention area previously contaminated and built	A			
	P5 - Percentage of green areas occupied by autochthonous plants	A+			
	P6 - Percentage in plan of area with reflectance equal or superior of 60%	A+			
C3 – Energy eficiency	P7 - Consumption of nonrenewable primary energy in the usage faze	A	0,956	39	0,373
	P8 - Quantity of energy from renewable energy source produced in the building	A+			
C4 – Materials and residual waist	P9 - Percentage in cost of re-used materials	B	0,929	22	0,204
	P10 - Percentage in weight of recycle content of the building	A+			
	P11 - Percentage in cost of organic base products that are certified	A+			
	P12 - Percentage in mass of substitutes of cement in the concrete	A			
	P13 - Potential of the condition building to allow separation and recycle	A			
C5 – Efficient usage of water	P14 - Volume of annual water usage per capita	A	1,069	8	0,085
	P15 - Percentage of reduction of the drinking water	A+			
	S= Performance in the Environmental Dimension				0,934

Table 4- Values for the Social and Economic Dimensions

Category	Parameters (PID)	Performance	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
C6 – Comfort and health of occupants	P16 - Potential of natural ventilation	B	0,943	60	0,566
	P17 - Percentage in weight of low COV materials	A			
	P18 - Annual level of thermal comfort	B			
	P19 - Average factor of the light in the medium day	A+			
	P20 - Average of acoustic insulation	A			
C7 – Acessibility	P21 - Index of accessibility of public transports	B	0,536	30	0,161
	P22 - Index of accessibility to amenities	A+			
C8 – Education for sustainability	P23 - Availability of the Usage manual of the building	A	0,967	10	0,097
	S= Performance in the Social Dimension				0,823
Life cycle cost	P24 - Initial value cost for m2 of usage area	A+	0,536	30	0,161
	P25 - Actual value of usage cost for m2 of area	A+			
	S= Performance in the Economic Dimension				0,823

Table 5 – Sustainability level of the building

Dimension	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
D1 - Environmental	0,934	40	0,374
D2 - Social	0,823	30	0,247
D3 - Economic	1,200	30	0,360
∑ = SustainabilityLevel (NS)			0,980

Analyzing the results it was verified that it could have been chosen more sustainable constructive solutions, but there were applied solutions that had a better thermal performance,because of the location and orientation of the building.

Due to the intention to integrate a garage in the back garden, the impermeabilization level related to the best practice was exceeded, but it was tried to maximize the green spaces with a green roof.

The systems of heating and cooling and of collection and treatment of the water, proved to be efficient, having reduced the cost of electric energy and drinking water.

Some of the interior materials couldn't be re-used because of the alterations that were made in the interior to maximize natural lightning.

The natural ventilation in the first floor due to the strait of the lot couldn't be moreimproved, but it was tried to promote some natural ventilation with the adjustable air vents implemented in the skylight.

In general, all the measures implemented promoted the sustainability of the building ,the final score of the building sustainability was A, which means that the building obtained a good level of sustainability, which was what it was intended.

4.5*Economic Viability of the Proposal Solutions*

Some of the system proposal solutions that were implemented revealed to have economic viability.

The system of collection and treatment of rain and bath water, with the flow controllers has a payback time of 6,8 years (Table 6), which is very good taking in consideration the durability of the system that is about 20 years. Due to the 50% reduction of drinking water use, the annual saving cost it is about 457,80 €.

The systems of heating, cooling and hot water implemented, in comparison to a propane system, revealed to havea payback time, for example, for the housing (I) of 6,9years, that it is very good taking in consideration the durability of the system (Table 6).

Table 6 –Payback time of the heating, cooling and hot water system of the housing (I)

Annual Saving (€) –Heat Pump	595,16
Total cost of the system of Heat Pump (€)	9.750,00
Total cost of the propane system (€)	5.600,00
Payback time (years)	6,9**

**considering that the cost is the same along the years, annual tax of 0% and that there is not any cost of maintenance along the years.

With the solution of using only LED bulbs for the artificial lightning, the annual saving concerning the cost with electricity, in comparison to conventional bulbs, is about 702,83€. The payback time of the LED lightning is about 1 year.

5 CONCLUSIONS

In this work it was shown the importance and the steps to the definition and inclusion of sustainable criteria's (environmental, social and economic) since the early stages of the refurbishment project, and how it can be a decisive factor in some situations. It is necessary that there is a planning phase, where can be evaluated all the components that make part of the building and in which we are going to intervene, to have more sustainable buildings.

During the development of the case study, it can be understood that it is the duty of the technicians to help the promoters to turn the buildings more sustainable, with the final goal to turn the society with more sustainable values.

The road to the development of more sustainable refurbishment projects reveals some difficulties, because it takes time to apply all the methodologies that was presented in this work, and some technicians probably will not be available to apply them. A challenge can be made for future development, which is to create a program that includes all the presented methodology and that will be easily apprehended by architects and other technicians.

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Thermal Rehabilitation for higher Comfort Condition and Energy Efficient Buildings

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ABSTRACT: Buildings rehabilitation and modernizing are measurements to improve living conditions and especially for energy saving in order to respect the standards of thermal insulation. In parallel with the reducing of energy demands it are realized two main objectives of a sustainable development such as a primary energy saving and the decrease of polluting emissions in the environment, the risk of condensation on the inside surfaces of exterior walls is removed and the thermal discomfort as effect of the cold asymmetric radiation is eliminated. The paper proposed the thermal analysis of 3 blocks of flats placed in Romania before and after their rehabilitation from energetically point of view and including aspects of the thermal resistances variation of exterior building elements. For these 3 analyzed buildings is compared the mean radiation temperature of the exterior surrounding elements in order to verify the appearance of condense and it are calculated the comfort parameters like the operative temperature, the PMV and PPD before and after the thermal rehabilitation.

1 INTRODUCTION

Buildings during time are considered in a continue evolution they must be rehabilitated and modernized in order to correspond to the demands established by users in a certain stage. At present of great inters are the analysis and interventions that concern energy saving and the assurance of adequate comfort conditions. In parallel with the reducing of energy demands it are realized two main objectives of a sustainable development such as a primary energy saving and the decrease of polluting emissions in the environment. In Romania the buildings made during 1960-1989 are great energy consumers because of their reduced values of heat transfer coefficients, in many cases the thermal comfort conditions are not assured and it exist the major risk of condensation on the inside surfaces of buildings.

Rehabilitation / thermal modernizing of a building represent an improvement method to maintain inside the heating energy. That means to add thermal insulation, tightness, improvement, even replace of windows and doors as well the improvement of equipment and installations of buildings. The paper analysis from thermal point of view three buildings of Romania placed in Resita town.

Energy consumption of buildings depends significantly on the criteria used for the internal environment, as temperature, ventilation and lighting and on the building design and operation, including systems.

A good indoor quality can improve men's performances, while uncomfortable occupants are likely to take actions to make themselves comfortable which may have energy implications.

2 CONSTRUCTIVE DESCRIPTION OF THE BUILDINGS

a) Block of flats placed on Tineretului street no. 3 in Resita town, built in the year 1966, with a number of 140 bachelor′s rooms, named as building no. 1. The building is of tower type with one underground and 10 over ground levels, with a rectangular shape. The utile heated area is 1472 m^2 and the utile heated volume is 4634 m^3. The main façade of the buildings is SE oriented, the roof is realized as a not circulated terrace composed by reinforced concrete plate, with thermal and hydro insulation. The exterior walls are made of reinforced concrete and they have mortar and painting layers. Finishing coat of floors is made of parquet and mosaic. Joineries are for the commune spaces with metallic frames, single pane glass window and the apartments have double pane glass windows with wooden frames. The buildings structural resistance is made in a mixed system with frames and diaphragms of reinforced concrete. The upper structure is entirely made by reinforced concrete; the diaphragms are realized by dragging technology and the floors are as prefabricated elements. The exterior diaphragms have a 20 cm thickness while the interior one is 16 cm thick. The not structural walls are made of cellular concrete with a thickness of 12.5 and 7 cm. The longitudinal facades and the parapets under windows as well as the exterior longitudinal frames are without thermal insulation. The floor that covers the underground level is with a thermal insulation made of cinder and with a hydro insulation. The exterior diaphragms are provided with cellular concrete plaque with 20 cm thickness as thermal insulation. The values of thermal resistances for exterior building elements are:

- Exterior walls 0.49 m^2K/W;
- Exterior windows in rooms 0.32 m^2K/W;
- Exterior windows of commune spaces 0.17 m^2K/W;
- Terrace floor 0.631 m^2K/W;
- Floor over the underground level 0.76 m^2K/W.

The mean thermal resistance of the building is 0.508 m^2K/W while the compactness index is 0.472.

Heat supply is assured by the town's centralized heating system. The interior heating system is made with cast-iron radiators as two pipes rising system.

b) Block of flats placed in 1 Decembrie Square in Resita town, with 36 apartments composed by 2, 3 and 4 rooms, built in 1987, named as building no. 2.

The building is of tower type with one underground and 9 over ground levels, with an almost square shape. The utile heated area is 3151.65 m^2 and the utile heated volume is 8509 m^3.

The main façade of the buildings is NV oriented, the roof is realized as a not circulated terrace composed by reinforced concrete plate, with thermal and hydro insulation. The exterior walls are made of reinforced concrete and they have mortar and painting layers. Finishing coat of floors is made of parquet, grit stone and Venetian mosaic.

Joineries are for the commune spaces with wooden frames, double pane glass windows and the apartments have double glazed windows with wooden frames, in some of them are thermo pane windows with plastic frames. The buildings structural resistance is made in a mixed system with frames and diaphragms of reinforced concrete. The upper structure is entirely made by reinforced concrete; the diaphragms are realized by dragging technology and the floors are as solid elements.

The exterior diaphragms have a 20 cm thickness; the not structural walls are made of cellular concrete with a thickness of 12.5 and 10 cm. The floor that covers the underground level is with a thermal insulation made of cinder and with a hydro insulation. The exterior diaphragms are provided with thermal insulation by cellular concrete plaque with 20 cm thickness.

The values of thermal resistances for exterior building elements are:

- Exterior walls 0.55 m^2K/W;
- Exterior windows with wooden frames 0.43 m^2K/W;
- Exterior thermo pan windows 0.55 m^2K/W;
- Terrace floor 0.45 m^2K/W;
- Floor over the underground level 0.76 m^2K/W.

The mean thermal resistance of the building is 0.531 m^2K/W while the compactness index is 0.37.

Each apartment has his own heating installation with a boiler Q=24 kW. The interior heating system is with steel or cast iron radiators and bathroom radiators.

c) Block of flats placed in Doman Street in Resita town, with 32 apartments composed by 1 and 2 rooms, built in the year 2009, named as building no. 3.

The building is a block of flats with one underground and 4 over ground levels, with a rectangular shape. The utile heated area is 4567 m^2 and the utile heated volume is 6020 m^3. The main façade of the buildings is east oriented and it has a ceramic tile roof. The exterior walls are made of bricks with 30 cm thickness and with a thermal insulation of 8 cm thick polystyrene, a mortar and painting layer. Finishing coat of floors is made of parquet and mosaic. Joineries are for the commune spaces and for the apartments made with thermo pane windows and plastic frames. The buildings structural resistance is made with resistant brick walls and kernel of reinforced concrete and concrete floors.

The not structural walls are made of efficient brick with 15 cm thickness. The floor that covers the underground level is with a thermal insulation made of extruded polystyrene with 10 cm thickness while the floor over the attic is with mineral wool panels with 20 cm thickness.

The values of thermal resistances for exterior building elements are:

- Exterior walls 1.58 m^2K/W;
- Exterior thermo pan windows with plastic frames 0.50 m^2K/W;
- Exterior thermo pan doors with plastic frames 0.55 m^2K/W;
- Attic floor 4.25 m^2K/W;
- Warm floor over the underground level 2.98 m^2K/W;
- Warm floor over the underground level 2.90 m^2K/W;
- Warm floor on the ground 4.40 m^2K/W;
- Warm floor on the ground 4.34 m^2K/W.

The mean thermal resistance of the building is 2.34 m^2K/W while the compactness index is 0.418.

3 ENERGETICALLY ANALISYS OF HEAT CONSUME

These buildings are placed in the climatic zone with -15°C outdoor calculus temperatures and in the IV wind zone with 4 m/s wind velocity.

Energy consume for buildings heating is calculated in function of the numbers of necessary heating days, established according to the average monthly outdoor temperature and the balanced temperature.

The calculation method in order to establish the annual thermal energy need for buildings heating is based on the standard SR ISO 13790 that transposes the European Norm EN ISO 13790.

The energetically balance includes the fowling terms (only the sensible heat is considered) [6]:

– Heat loses through transmission and ventilation from the heated environment to the outdoor; ;
– Heat loses through transmission and ventilation between neighbor zones;
– Internal utile heat gains;
– Solar gains;
– Heat losses related to the producing, distribution, heat emission and for regulation of the heating system;
– Input energy in the heating system.

The total heat transfer of a building as single-zone with assuring a uniform indoor temperature for a calculation period is established with the relation [2], [3]:

$$Q_L = H \times \left(\theta_i - \theta_e\right) \times t \quad (1)$$

Where:

θ_i is the indoor conventional temperature;

θ_e is the outdoor mean temperature during the calculation period (outdoor mean monthly temperature or for the heating season);

t is the calculation period;

H is the heat transfer coefficient of the building.

The heat transfer coefficient of a building as single-zone, with assuring a uniform indoor temperature for a given calculation period or less, is defined with the following relation:

$$H = H_T + H_V \tag{2}$$

Where:

H_T is the transmission heat transfer coefficient, calculated according SR EN 13790/2005;

H_V is the ventilation heat transfer coefficient.

The internal heat sources Q_i, is the sum of all internal heat sources in the heated space, other than the heating system:

– Metabolically heat gain from occupants;
– Heat gains from apparatus and electrical lightning.

It is recommended to use the mean monthly values or the values for the heating period. The calculating relation is [2]:

$$Q_i = \left[\Phi_{i,h} + (1-b)\,\Phi_{i,u}\right] t = \Phi_{i\,t} \tag{3}$$

Where:

$\Phi_{i,h}$ is the mean heat flow rate for internal gains in heated spaces;

$\Phi_{i,u}$ is the mean heat flow rate for internal gains in unheated spaces;

Φ_i is the mean heat flow rate for internal heat gains;

b is a reduction factor defined in SR EN ISO 13790.

The soar gains depends on the solar radiation, normally present on the respective placement, depending on the orientation of the receiving surfaces, on the permanent shadowing, on the transfer and absorption characteristics of the solar receiving surfaces. As receiving surfaces are considered the glazing, the internal walls and the floors of sunspaces, the walls placed behind a transparent covering or a transparent insulation. For the opaque surfaces exposed on solar radiation it must be consulted the attachment F.

For a given calculation period, the solar gains are calculated with the relation [2]:

$$Q_S = \sum_j \left[I_{sj} \sum_n A_{snj} \right] + (1-b) \cdot \sum_j \left[I_{sj} \sum_n A_{snj,u} \right] \tag{4}$$

In this relation the first term is for the heated space and the second term for the unheated space. The solar gains from the unheated spaces are multiplied with (1-b), where b represents the reduction defined in factor SR EN ISO 13789.

In each term the first sum is made for all the j orientations while in the second term for all the n surfaces that receives the solar radiation , where :

I_{sj} is the solar radiation, for example the total energy of solar radiation globally during the calculation period for 1m² surfaces with the j orientation, in J/ m²;

A_{snj} is the equivalent receiving area of the surface n with the orientation j, it means the area of a black body that leads to the same solar gains as the considered surface.

The energy need for heating (O_h) is determined for each calculation period/season with the relation:

$$Q_h = Q_L - \eta Q_g \tag{5}$$

Where:

– Q_L is the heat losses,
– η is the utilization factor
– Qg is the heat gains.

For the calculation of these heat losses the following subsystems of the heating system are considered:

– The heat transfer (emission) system to the consumer, including the control and regulation devices;
– The heat distribution system to the consumer, including the control and regulation devices;
– The storage system, including the control and regulation devices (if it exist);
– The heat generating system (for buildings with individual heating sources), including the control and regulation devices.

The total heat losses of a heating system in a building Q_{th}, is expressed as sum of heat losses for all of the above mentioned subsystems, thus:

$$Q_{th} = Q_{em} + Q_d + Q_s + Q_g \tag{6}$$

Where:

Q_{em} is the heat losses caused by an un-ideal heat transfer system to the consumer, in J;

Q_d is the heat losses of the distribution system to the consumer, in J; the value of this heat losses depends on the configuration of the distribution network system, on there placement, on the insulation type, on the flow temperature, on the types of control and regulation devices i.e.

Q_s is the heat losses of the storage system (if it exist), in J;

Q_g is the heat losses of the generating system during the functioning period.

The total energy consume for heating is obtained as a sum of the terms presented in the former paragraphs, respectively:

$$Q_{f,h} = (Q_h - Q_{rhh} - Q_{rwh}) + Q_{th} = Q_h + Q_{em} + Q_d - (Q_{rhh} + Q_{rwh}) \tag{7}$$

Thus, for building no. 1 on Tineretului Street results a number of 220 heating days, for building no. 2 on 1 Decembrie Square a number of 216 heating days and for building no. 3 on Doman Street a number of 204 heating days. Energy consume for heating is determined for each month of the heating period. For the building no. 1 the heating season begins at the 26th of September until the 5th of May, for the building no. 2 it begins at the 28th of September until the 3rd of May and for the building no. 3 it begins at 4th of October until the 25th of April.

The annual specific heating energy consume is:

- Building no. 1 with 201 kWh/m^{2}year, energetically class D and 48.2 kg CO_2/m^2 year emission of CO_2.
- Building no. 2 with 151.9 kWh/m^{2}year, energetically class C and 30.4 kg CO_2/m^2 year emission of CO_2.
- Building no. 3 with 112.1 kWh/m^{2}year, energetically class B and 22.4 kg CO_2/m^2 year emission of CO_2.

It is made a thermo graphic analyses of building no. 1, with the following air parameters:

– Indoor air temperature t_i=+20.5°C;
– Outdoor air temperature t_o=-5°C;
– Relative humidity hr=95%.

4 BUILDING THERMAL REHABILITATION

According to the energy consume and thermal resistances of the buildings no. 1 and no. 2, it is necessary there energetically rehabilitation. Thermal rehabilitation of the buildings no. 1 and 2 needs a series of measurements to reduce the heat loses through the exterior buildings elements by increasing the heat transfer resistance, as follows:

- Terrace – the existent thermal and hydro insulating layers will be removed and it will be applied a cold bituminoid emulsion, basaltic mineral wool of 12 cm thickness, hydro insulating membrane.
- Walls – the exterior damaged mortar layer will be repaired, it will applied an adhesive layer for fixing an 8 cm thick polystyrene, a fiberglass bats covered with an adhesive, grunt layer and decorative mortar.

Exterior windows will be replaced with low-e and argon glazed windows and plastic frames.

In table 1 are presented the values of thermal heat resistances for the rehabilitated building elements. The corrected thermal heat resistances are determined according the correction coefficients for materials conductivity.

After the buildings rehabilitation, a thermal examination gives the following annually specific heating energy consumes:

- Building no. 1 with 116 kWh/m^{2}year, energetically class B and 28.1 kg CO_2/m^2 year emission of CO_2, that assures a reduce of thermal energy with 42% and a reduce of CO_2 emissions with 41%.
- Building no. 2 with 101 kWh/m^{2}year, energetically class B and 19.9 kg CO_2/m^2 year emission of CO_2, that assures a reduce of thermal energy with 34% and a reduce of CO_2 emissions with 33%.

- Building no. 3 does not need thermal rehabilitation measures, it has an annually specific heat consume of 112.1 kWh/m^{2}year and it is placed in the energetically class B.

Table 1 Thermal heat resistance of exterior building elements

Building elements	Building no.1	Building no.2	Building no.3
	Rehabilitated m^{2}K/W	Rehabilitated m^{2}K/W	Existent m^{2}K/W
Terrace floor	3.05	3.28	4.25
Exterior walls	1.41	1.55	1.58
Floor over underground level	1.68	1.71	2.90
Windows	0.55	0.55	0.55

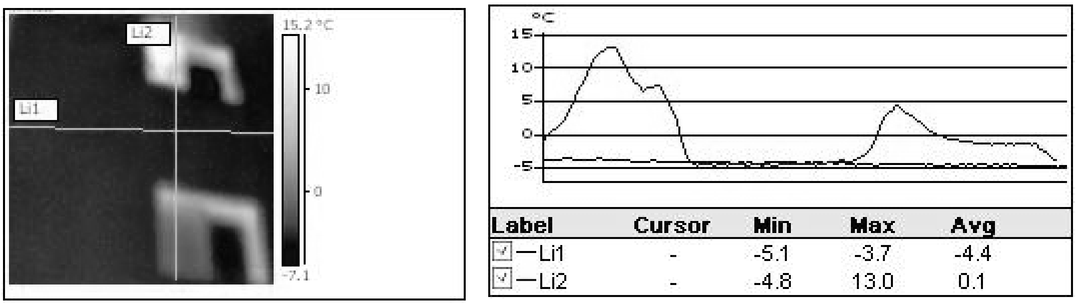

Fig. 1 Temperature variation at the inside rehabilitated wall surface for building no. 1

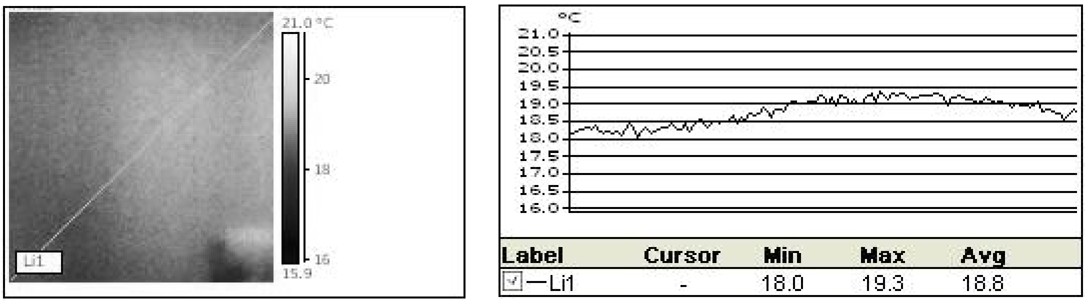

Fig. 2 Temperature variation at the inside rehabilitated wall surface for building no. 1

As observed in fig. 1 the temperature on the opaque outside rehabilitated surface is nearly constant by a t_{wo}=-4.4°C value. Thus, the thermal bridges on the opaque surface are reduced and the thermal resistances increase 2.87 times. For this conditions, as presented in fig. 2, the temperature on the inside wall surface has an average value of t_{wi}=+18.8°C, value that respects the given temperature difference between indoor air and inside surface of exterior elements. Therefore the risk of condensation is reduced by a relative humidity greater than 85%, situation that occurs when rooms are insufficient ventilated and the fresh air is not assured.

Thermal comfort is largely a state of mind, separate from equations for heat and mass transfer and energy balances. However, the perception of comfort is expected to be influenced by the variables that affect the heat and mass transfer in our energy balance model. The most common approach to characterizing thermal comfort for the purposes of prediction and building design has been to correlate the results of psychological experiments to thermal analysis variables. The level of comfort is often characterized using the ASHRAE thermal sensation scale. The average thermal sensation response of a large number of subjects, using the ASHRAE thermal sensation scale, is called the predicted mean vote (PMV).

The recommendations made by ASHRAE Standard 55 are shown in Table 2. These thermal conditions should ensure that at least 90% of occupants feel thermally satisfied.

Table 2: ASHRAE Standard recommendations.

Season	Operative temperature [°C]	Acceptable range [°C]
Winter	22	20 - 23
Summer	24.5	23 - 26

PPD means Predicted Percentage of Dissatisfied and is an indication of the percentage of people who could complain about the thermal quality of a given indoor environment.

For the former building no.1 PMV and PPD is calculated in table 3.

Table 3 Input and results parameters for thermal comfort

Parameter	Input	Parameter	Results
Clothing [clo]	1.10	Operative temp. [°C]	18.8
Air temp. [°C]	20.5		
Mean radiant temp. [°C]	17.1	PMV	-1
Activity [met]	1.0		
Air speed [m/s]	0.15	PPD	26.1
Relative humidity [%]	57		

For rehabilitated building no.1 PMV and PPD is calculated in table 4.

Table 4 Input and results parameters for thermal comfort

Parameter	Input	Parameter	Results
Clothing [clo]	1.10	Operative temp. [°C]	20.3
Air temp. [°C]	21.8		
Mean radiant temp. [°C]	18.8	PMV	-0.5
Activity [met]	1.0		
Air speed [m/s]	0.15	PPD	9.7
Relative humidity [%]	55		

5 CONCLUSION

Thermal rehabilitation of civil buildings in Romania, built during 1960-1989, is a necessity in order to reduce heat losses during the winter period and to realize corrected thermal resistance values of building elements close to European one.

Due to this rehabilitation process the risk of condensation on the inside surfaces of exterior walls is removed but it is conditioned by a periodical room’s ventilation. Also, the thermal discomfort as effect of the cold asymmetric radiation is eliminated.

Concerning this two analyzed buildings, the specific heating energy consume decreases with 41% for building no. 1 and with 33% for building no. 2, that leads to a reduce of the bills account for thermal energy consume and to a reduce of CO_2 emission in the burnt gases during thermal energy producing.

As presented in the tables 3 and 4, the operative temperature for the non-rehabilitated buildings is below the inferior limit of the allowed temperature range, while after the rehabilitating process of the buildings envelope and modernizing of the thermal installations, the operative temperature is in the recommended temperature range, as for the PMV value it corresponds for thermal comfort assurance.

The building no. 3 realized in 2009 has the energy consume in the given domain ranges and it respects the given values for the thermal resistances of exterior building elements.

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Energy efficient envelope for renovation of terraced housing

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ABSTRACT: This paper presents a synthesis of the most relevant results of a study carried out by the Department of Architecture, University of Bologna, concerning the potential of energy retrofitting actions on existing terraced homes. This research proposes a preliminary analysis of the users' behavior in relation to the building functional features and energy demand. A set of different conditions concerning the layout, the functionalities and the upgrading of systems was listed and their related costs - in terms of maintenance and energy costs - were highlighted. A case study of reference was selected, amongst the several ones analyzed during the research. The selected building is located near Bologna (IT) and was built in the early 70's, therefore it is 50 years old and not up to today's energy Standards with an overall performance index of more than 206 kWh/m^2 per year. Some innovative renovation strategies were investigated in order to provide both an increase in volume and surface and quality of the building as well as an improvement in energy efficiency, in order to drastically reduce the energy demand. A step by step implementation approach is developed starting from the increasing in energy performance provided by the building envelope and according to the level of the tenants' awareness with the final aim to reach high energy performance standards.

1 INTRODUCTION

1.1 *General framework*

The European Council conclusions of 10 June 2011 on the Energy Efficiency Plan 2011state that the building sector is estimated to be responsible for 41% (or more, depending on the calculation criteria and the considered boundaries) of the total energy consumption in the EU, of which 27% for residential buildings. The European Parliament and the EU Council promoted a wide range of improvements as concerns the buildings energy performance, through the Directives 2010/31/EU and 2012/27/EU, proposing a methodology taking into account climate and local conditions, as well as indoor climate requirements and cost-effectiveness. The housing stock is composed of heterogeneous buildings, with different age, typologies and dimensions and consequently with different construction systems and technologies applied. The Housing Statistics in the European Union (Dol, Haffner 2010) shows that the largest part (46%) of the housing stock was built between the end of the Second World War and the 70's to meet the post-war demand. This means that almost half of the total housing stock is more than thirty years old and starts to show signs of its physiological obsolescence. If the stock built during the 80's and the 90's – as a result of the economic growth – is also considered, the share increases to more than 65% meaning that two third of the housing stock is totally or partially inadequate in meeting the current standards in terms of thermal behavior, energy efficiency, quality and comfort. Only a very small part (6%) of the stock was built after the year 2000 and should have been designed with sustainable and energy efficient criteria. So the EU Parliament efforts are focused on supporting the renovation of the existing building stock in terms of energy efficiency (Economidou, 2011).

The largest part of the conventional Italian building stock was developed between the 60's and the early 90's and consequently is affected by relevant technical obsolescence (both physical and functional) and by a very high level of energy consumption (150-200 kWh/m^{2}y) (Di Giulio 2010). Furthermore, large part of these buildings turned out to be unsuitable in meeting the needs of modern families and their changed lifestyle. National statistical data shows that half of the households live in a one family house (and great part of the rest of the population would like to as well) or in a detached house or in terraced housing which is one of the prevalent typology at national scale; traditionally built using very conventional construction systems, this stock is characterized by very high running costs related to heating and cooling and to ordinary/extraordinary maintenance needed.

1.2 *Contents and research objectives*

A research program, currently ongoing at the University of Bologna, Department of Architecture, is investigating new retrofitting strategies, in accordance to emerging requirements and high-energy efficiency standards, for renovating the existing building stock (Boeri et al. 2012). A branch of this study is focusing on assessing the opportunities of intervention in terraced housing, as this typology is recurrent in housing estates belonging to the 60's - 90's, as well as in the most recent neighborhoods.

A first phase of this research focused on the analysis of the users' behavior in relation to the building functional features and energy needs. It was noted that in most cases householders expressed a very low satisfaction level in relation to their current needs and how their house met them. These results are mainly related to functional features and to the limits of adaptability of the dwelling to the emerging requirements due to new lifestyle and new family models. An improvement of indoor comfort conditions is often not perceived as a priority compared to the desire of having new additional and functional spaces.

So the starting assumption during preliminary investigations was that users can't be interested in the energy issue if they are not aware of its related implications in their everyday life. Therefore, the goal of this first phase was to understand which tasks are perceived as most urgent for the renovation and the priority level assigned to the energy issue. Once the households' main expectations were set, the second phase of this study focused on evaluating the pathologies and deficits affecting the building in order to point out the main objectives of the refurbishment interventions.

Then a simulation model was used in order to compare the different solutions to be adopted to achieve these objectives, such as assessing the cost-effectiveness of the interventions as well as the energy efficiency improvements obtained.

The main aim of this study is to obtain effective criteria for approaching the retrofitting actions in this specific field taking into account the typical and peculiar features of the Italian terraced housing stock.

2 METHODOLOGICAL OVERVIEW

2.1 *Setting up the requirements*

During preliminary studies, a set of different conditions concerning the layout, the functionalities and upgrading of systems was listed together with their related costs (maintenance and energy costs). Prioritizing households' expectations in relation to the results of a refurbishment actions means analyzing their availability in investing for the transformation and/or upgrading of specific elements in their house.

The most recurring expectations concern the availability of additional and functional spaces obtained by transforming the existing buildings' layout or by extending it through the introduction of new volumes. These additional spaces are described as related to leisure, entertainment, fitness, personal care, etc. and can be clearly considered as a result of an evolution in lifestyle. Despite the financial crisis of 2008 and its impact on families' economic conditions, these additions still represent the first segment of investment for many people.

A second priority expressed by users regards the control of indoor conditions and, especially, cooling during summer which in most cases is provided (at a very reasonable cost) by resorting to a single external heat pump unit. Naturally, this is not the most suitable solution from a sustainable point of view, even if it meets the users' requirements. Other expectations concern the finishing and materials as well as an upgrade of fittings and systems.

Unfortunately, only a small part of households shows to be aware of the implications of the energy issue in terms of environmental impacts and operating costs. The attention of owners/users to the energy issue increases when this concept is linked to the resulting financial benefits.

After investigating the requirements these were grouped in main tasks and related specific retrofitting actions were developed. Table 1 summarizes tasks and actions groups.

Table 1. Defined tasks and related actions to be developed in the design stage.

Preliminary design analysis	
Tasks	*Possible actions*
additional spaces	structural and technological analysis morphological and geometrical evaluations introduction of new volumes transformation of layout
thermal condition control	building envelope implementation orientation and exposure adequate insulation layer passive and active solar gain natural ventilation strategies thermal transmittance evaluation
technical upgrade	heating system cooling system additional equipment system for integrated renewable energy sources an assessment of energy performance
general refurbishment	finishing choice of sustainable materials

The effectiveness of each task and related actions is to be assessed in terms of cost effectiveness and resulting benefits in terms of energy efficiency performance. The goal is to show households the benefits of retrofitting actions involving energy efficiency in terms of a reduction in operating costs and therefore inducing a higher level of awareness for a more sustainable design approach.

2.2 *Defining retrofitting strategies*

Once the tasks of the renovation interventions are set, a simulation model is used to compare different strategies, assess the efficiency of the building envelope implementation, evaluate energy performance and develop specific technological solutions according to the morphological and geometrical features of each building. The research includes the study of terraced housing estates in Italy and foresees a multi-criteria design approach leading to two different retrofitting scenarios.

The first scenario aims at increasing the performance of the building envelope through the implementation of its stratigraphy, introduction energy efficiency measures, with no consideration for the priorities set by the households priorities related to the use of spaces.

The second scenario is an upgrade of the first one, however providing some additional spaces through volumetric additions. For both of these a cost effectiveness evaluation and an energy performance assessment are carried out.

3 APPLYING THE DESIGN APPROACH TO A CASE STUDY

3.1 *Case study description*

The case study, named Bel Poggio Neighbourhood, is located in San Lazzaro, a district close to Bologna, built in 1973. It is affected by several deficit concerning thermal and acoustic insulation as well as many pathologies due to its natural ageing (Boeri et al. 2010). The building combines the general features of the terraced house typology with some specific characteristics at national and local level. It consists of a series of units arranged by following the curved line of the site, producing a staggering of the plan and of the section. This terraced housing estate is east-west orientated and the main brick fronts (typical in this geographical area) feature a wide openings on the ground level and on the last floor conferring a peculiar morphological effect to the main façade, as figure 1 shows.

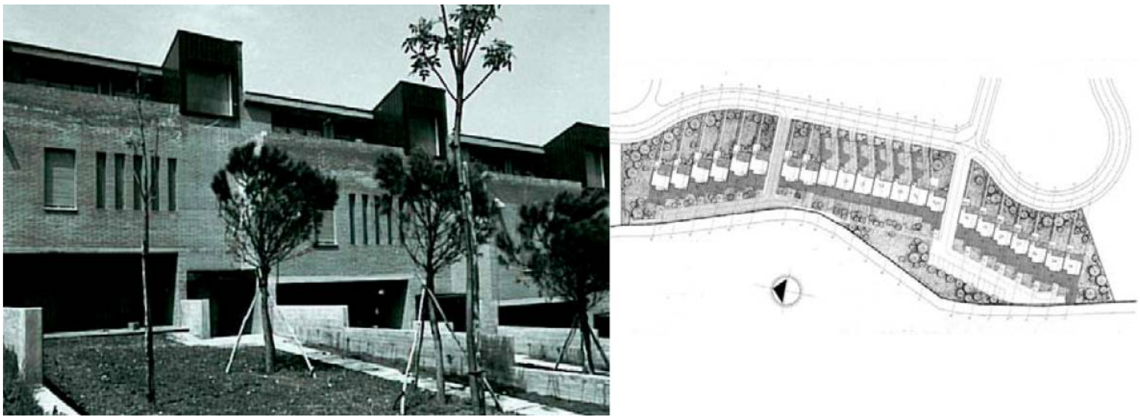

Figure 1. View of the main front and general plan of site.

The houses develop on four levels and the ground configuration of the site affects the shape of this estate. A preliminary energy assessment resulted in overall performance index of the unit of more than 206 kWh/m^{2}y, higher than the average value for the Italian existing building stock. The needs for heating during winter reach 183 kWh/m^{2}y, while hot water production requires 23 kWh/m^{2}y. Energy losses mainly affect the two fronts on the east and west sides (about 30% of the total), the roof (12%) and the ground floor (13%).

3.2 *First renovation scenario*

The retrofitting action acts on the building envelope without modifying the exteriors in order to preserve the main features of the housing estate. The main feature of these buildings is they are brick front, a very recurring feature in Italian cities, representing however a specific constraint, requiring the adoption of special technological choices (Antonini et al. 2012).

A new insulation layer is applied on the external wall from the inside by using dry technologies and innovative materials. The insulation layer specifications and thermal transmittance were calculated using a simulation model corresponding to the shape and geometry of the external closures. This intervention allows to adapt this strategy to the majority of operational contexts, even if less effective and technically more difficult. The use of partially prefabricated lightweight components could speed up the construction phases and achieve a higher and more controlled technical level.

All the technical choices were focused on maximizing energy efficiency, and – at the same time – they were thought in such a way to make them adaptable to other building typologies and at affordable costs. Double glazing windows (Uw=1.3 W/m^{2}K) were selected instead of high performing triple glazing ones due to the average performance of the building envelope and to limit costs. As figure 2 shows, the concept is to create a thermal barrier through the existing elements, and corresponds to the red line in the section. However, the geometry of the building doesn't allow for totally avoiding thermal bridges and the effectiveness of this solution is affected by the materials applied.

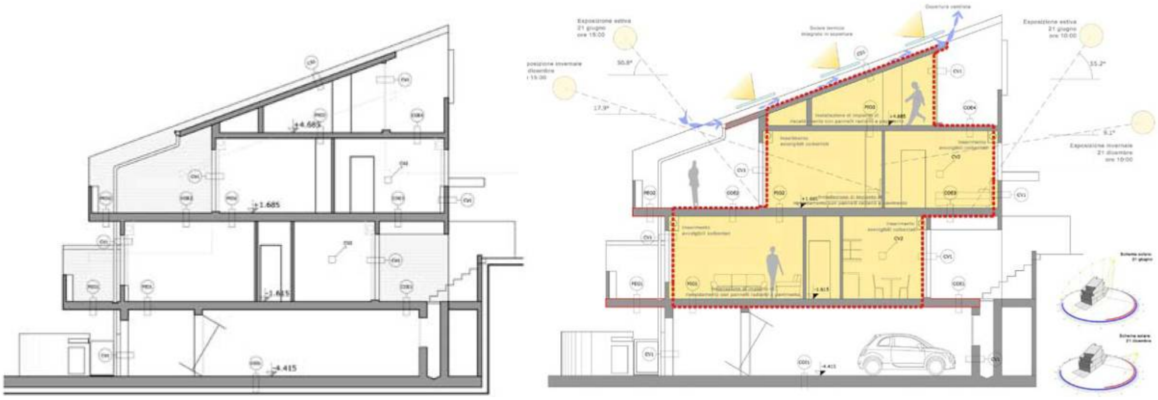

Figure 2. Cross section before and after intervention.

After intervention the energy assessment gave the unit an overall performance index of 50.68 kWh/m^{2}y, reducing the total energy demand to less than a quarter (24, 60%) then the original one.

3.3 *Second renovation scenario*

The second scenario evaluates the possibility of creating additional surface in the building: some balconies and volumes are installed on the façades and on the roof of each unit, so that the units floor area could be increased by as much as 20 to 35%. This would satisfy one of the most recurring households' request however it naturally requires a greater investment. Therefore this would represent a suitable option only in light of a major renovation intervention involving a drastic increase of energy performance (Gaspari 2012).

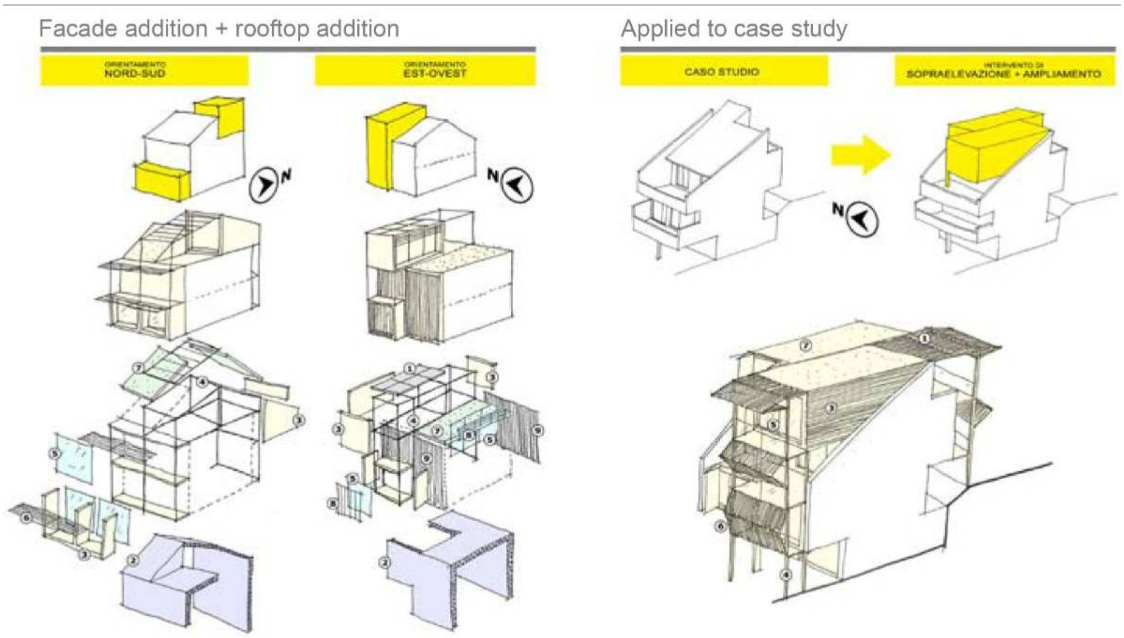

Figure 3. Sketches of the study concerning the volumetric addition of terraced housing units.

After the shape and the construction system of the additions are defined, the simulation model is used for assessing the energy efficiency of the whole building and evaluating the improvement derived from passive and active solar gains (solar collectors and photovoltaic systems can be integrated on the roof and on the new volumes). Natural ventilation and shading systems are provided in order to improve the building envelope behavior during summer. The final layout allows for very flexible solutions and, where required, allows to obtain, for each unit, an additional independent small flat, suitable for extended families (elderly relatives, children).

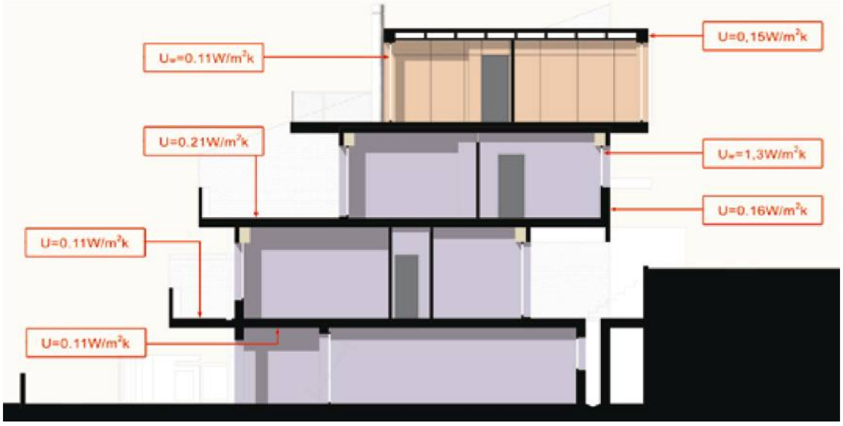

Figure 4. Layout of thermal transmittance value of the principal elements of the simulation model.

The energy assessment of both existing and added volumes, combined, gives an overall energy performance index of 43.37 kWh/m^2y, reducing the energy demand by one-fifth (21%) when compared to the initial conditions. The additions are provided trough the application of dry technologies in order to ease the integration with the existing structures, speed up the transformation phase, allow for reversibility, and obtain a high level of performance and efficiency at low cost.

Figure 5. View of the two options of addition during simulation.

According to the refurbishment intervention on each unit, a simulation is performed in order to evaluate the impact of the volumetric additions on the overall elevation of the building, taking into consideration different solutions and different density of added volumes (Druot et al. 2007). The simulation model is been therefore used to assess the impact of the new volumes on the building shape and with reference to the existing light box above the entrance, as well as to check the solid/voids variations.

There are two different options: one maximizing the opportunities for addition, by creating a new volume with a flat roof, through the replacement of part of the existing roof and terrace; the second one aims at reducing the impact of the renovation action by following the shape of the existing roof, limiting the new volume to the terrace.

For both of these options, the main difference as regards the starting condition, is the loss of the gap at the top of the façade, deriving from the shape produced by the roof which was aimed at balancing the basement one in the original design. In both cases the new volume, emerging from the principal elevation, offers a natural shading of the openings at the intermediate level.

All the openings of the additions are provided with a shading system to reduce overheating during summer.

Reproducibility was also investigated in a more general framework.

Figure 6. Compared cross section and main elevation of the two options of volumetric addition.

As figure 6 shows, both the proposed solutions present variation of the elevation in order to emphasize the staggered plan foreseen by the project, while they are completely different in terms of quality of space as you can see in the cross sections.

Producing the same improvement in terms of energy efficiency and savings: both of these options appeal much more to the households rather than a simple implementation of the building envelope. This type of intervention costs 60% less than a major renovation one, however it doesn't provide instant benefits in terms of availability and functionality of spaces.

4 CONCLUSIONS

This paper offers the first results of a study on effective renovation strategies for existing terraced housing stock in Italy. Still in its early stages, this research highlights the gap between the expected effects of renovation processes, according to the goals of the European Directives, in terms of energy saving measures, and the households' actual expectations, in terms of quality level, deriving from retrofitting actions. A complex framework emerges, in which the improvement on comfort and living conditions, deriving from the retrofitting action, are far from being perceived as the main benefit of the renovation process by householders, while financial aspects and directly achievable functional advantages are still considered a priority.

Starting from the analyzed case studies and related performed simulations, a step-by-step design strategy was developed in order to obtain significant energy savings and functional advantages. A major renovation action, based on volumetric additions, it's possible only after the implementation of the existing building envelope.

The methodology adopted aims at allowing the planned refurbishment actions and reducing the use of primary resources while maximizing the useful life of components. Some new criteria could be introduced during the design stage. The idea of designing a building that can be transformed through time stems from the use of removable technological solutions, such as dry and pre-assembled systems, and also from a special different view on the relationship between the building different elements and its sub-systems.

An interesting issue, emerged during this study, highlighted the factors that influence the confidence of the households in investing in renovation processes. Even if payback time seems to be the main criteria of choice, the level of satisfaction concerning functional and spatial requirements rather than the performance ones, has a very relevant weight in the decisional process. So this issue has to be suitably considered in the preliminary stage of the renovation project, introducing clearer communication strategies in order to make the user/investor more aware of the benefits related to energy efficiency, of their relation with the relevant standards and of the impact renovation has on the building as a whole.

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Chapter 8

Eco-Efficient Materials and Technologies

Using MCDA to Select Refurbishment Solutions to Improve Buildings IEQ

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ABSTRACT: Due to buildings high energy consumption their refurbishment is essential to achieve the targets defined by the EPBD-recast regarding energy efficiency and reduction of carbon emissions. Besides the energy efficiency, the sustainability and the Indoor Environmental Quality (IEQ) of Buildings must also be considered when planning a refurbishment project. Thus, to propose an effective building refurbishment it is necessary to select the adequate construction solutions taking into account their impact on the energy performance, thermal and acoustic comfort, indoor air quality and environmental impact of the building. In this work a multi-criteria decision analysis method is applied to balance all these aspects in a refurbishment project, in order to assist the design team on the selection of the construction solutions. Throughout the multi-criteria analysis performed, it was possible to verify that the rehabilitation solutions with lower embodied energy were the best refurbishment options.

1 INTRODUCTION

Energy efficiency and indoor environmental quality of buildings are nowadays major concerns as European Union (EU) buildings account for 40% of the total energy consumption (EPBD 2002) and the population spends about 90% of their time inside closed spaces. Thus, it is mandatory to control the energy consumption in the building sector, while improving the indoor environmental quality (IEQ), to reduce these needs and, consequently, reduce the EU energy dependency as well as the greenhouse gas emissions, in accordance with what is prescribed in the Energy Efficiency in Buildings Directive (EPBD) and reinforced with the "EPBD recast" (EPBD 2002; EPBD-recast 2010).

The rehabilitation of the building stock is an opportunity to achieve these goals. In Portugal, 80% of the building stock was built before 1990 (Census 2011), year of the publication of the first Portuguese thermal regulation, leading to high levels of thermal discomfort and excessive energy consumption, as the majority of the existing buildings was built without any thermal concerns and shows very high energy consumptions even when minimal comfort conditions are required.

To correctly select the rehabilitation construction solutions it is necessary to consider their contribution to the energy efficiency, thermal and acoustic comfort, daylight conditions and the indoor air quality, its environmental impact (considering the embodied energy, for example), but also their contribution to the thermal inertia of the building and the thickness as the useful area might be reduced.

However, these goals are often in conflict and there is not a unique criterion that describes the consequences of each alternative solution adequately and there is not a single solution that optimizes all criteria. In many cases, the best solutions to accomplish different comfort requirements are not compatible, especially in what concerns natural ventilation and daylighting strategies and the acoustic and thermal comfort. For instance, the type of window used can have a strong and opposite influence on the thermal and acoustic performance of the building, just not to mention its interference with the indoor air quality (IAQ). It is, then, necessary to have an integrated approach to ensure the best overall behaviour taking into account all of the, sometimes incompatible, comfort and energy efficiency requirements.

Thus, to propose an effective building refurbishment it is necessary to select the adequate construction solutions and materials taking into account their impact on the energy performance, thermal and acoustic comfort, indoor air quality and environmental impact of the building.

Therefore, thermal quality, acoustic behaviour and energy reduction strategies, that are mandatory, should be meshed at an early stage of the rehabilitation process with the other requirements to ensure the buildings overall comfort conditions and energy efficiency. To do so, it is necessary to select the correct materials, and construction solutions, among a large number of options to improve the occupants overall comfort and, at the same time, reduce the energy costs. Furthermore, to make a conscious selection of the possible alternatives, it is necessary to balance the positive and negative aspects of each solution into the global behaviour of the building trough a multi-objective optimization.

The correct comparison of the solutions is difficult as the behaviour of some are affected by imprecision (design phase) and it is also necessary to take into account the constraints of the project and the decision maker point of view.

Multi-criteria decision analysis (MCDA) is, in this way, an important tool in such problems, since it can be used in any location and employs mathematical models that evaluate alternative scenarios, taking into account both their objective characteristics (acoustic insulation, U-Value, etc.) and the preferences of the decision makers regarding the objectives and constraints of each project.

The aim of this study was to select the materials and construction solutions to refurbish the façade walls of a building, based on criteria that are mandatory (thermal and acoustic insulation) and the designer must conciliate. The embodied energy, superficial mass and thickness of the construction solutions were also considered as they are a designer concern, affecting the environmental impact, the thermal inertia and the useful area of the building. In this work the MCDA method ELECTRE III (Roy 1978) was chosen to assist the design team in the selection of the most adequate refurbishment solutions.

2 METHODOLOGY

To achieve an adequate behaviour of the buildings it is necessary to consider the indoor environmental quality, the environmental impact as well as the energy efficiency. It is then essential to optimize the building envelope, by improving construction solutions and insulation levels, glazing type, optimizing the thermal and acoustic behaviour, the natural ventilation and daylighting techniques through an appropriate refurbishment project. In this study several construction solutions for the refurbishment of façade walls were studied.

2.1 *Retrofit Building Characteristics*

The case-study building to be refurbished is a 1980s' single family detached house (Fig. 1).

The building, with two bedrooms, 54.42 m^2 and 2.44 m of floor to ceiling height, is north oriented. The construction system is a low cost construction system based on a steel reinforced concrete pillars and beams structure, single pane hollow concrete block walls and clear single glass with aluminium frame windows with PVC (Polyvinyl chloride) roller shutters. The window to wall ratio (ratio between the area of the window and the area of the wall) is approximately 20%. Table 1 lists the main characteristics of the building envelope.

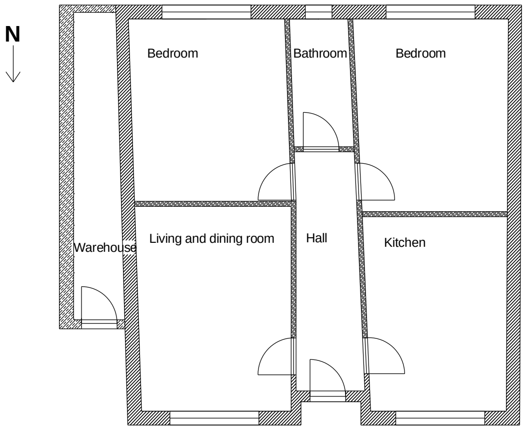

Figure 1. Floor plan of the building

Table 1. Characteristics of the building

Building element	Construction solution	U-value [W/(m^2°C)]
Structure	Concrete pillars and beams	-
Floors	Concrete	-
Roof	Pitched roof	2.35
Ceiling	Beam and pot slab	3.08
Façade walls	Single pane hollow concrete block	1.90
Roller shutter boxes	concrete	2.85
Windows (window to wall ratio of 20%)	Single clear glass and aluminium frame	5.14
Partition walls	Hollow brick	-

2.2 *Multi-criteria analysis*

The multi-criteria decision analysis defines flexible approach models to help the decision maker, and/or the design team, to perform a multi-objective optimization to select the most adequate solutions to optimize the building's IEQ and energy efficiency among a large number of options and possibilities. The problem of the decision makers is a multi-objective optimization problem characterized by the existence of multiple, and in several cases competitive, objectives that should be optimized, taking into account a set of parameters (criteria) and constraints (Ehrgott & Wiecek 2005).The MCDA methods can be applied when there are several decision agents, each one with different objectives and criteria, sometimes with opposite visions.

This kind of analysis is able to reflect the objectives and limitations of each one of the alternatives to be studied, but it is necessary to be thorough on selecting the criteria that should be exhaustive but not redundant (it is recommended to use no more than 12, which represents an acceptable compromise between feasibility and detailed description) and must be coherent (which are the criteria to be maximized and to be minimized) (Roy & Bouysson 1993, Roulet et al. 2002).

The MCDA method selected in this work to help the decision maker selecting the most adequate solutions to optimize the building indoor environmental quality and energy efficiency, was the ELECTRE III (ELimination Et Choix Traduisant la REalité - ELimination and Choice Expressing the REality) model as it may be considered as a decision-aid technique suited to the appraisal of complex civil engineering projects (Roy 1978, Papadopoulos & Karagiannidis 2008).

2.2.1 *The ELECTRE III method*

ELECTRE III is a multi-criteria decision analysis method that takes into account the uncertainty and imprecision, which are usually inherent in data produced by predictions and estimations (Roy 1978). The construction of an outranking relation amounts at validating or invalidating, for any pair of alternatives (a, b), the assertion "a is at least as good as b". This comparison is grounded on the evaluation vectors of both alternatives and on additional information concerning the decision maker's preferences, accounting for two conditions: concordance and non-discordance.

The ELECTRE III method is based on the axiom of partial comparability according to which preferences are simulated with the use of four binary relations: I, indifference; P, heavy preference; Q, light preference and R, non-comparability. Furthermore, the thresholds of preference (p), indifference (q) and veto (v) have been introduced, so that relations are not expressed mistakenly due to differences that are less important (Roy 1978).

The indifference threshold (q) defines the value beneath which the decision maker is indifferent to two option valuations, the preference threshold (p) defines the value above which the decision maker shows a clear strict preference of one option over the other, and the veto threshold (v) where a 'discordant' difference in favour of one option greater than this value will require the decision maker to negate any possible outranking relationship indicated by the other criteria. The indifference (q) and preference (p) thresholds of any criterion can also be interpreted as the minimum imprecision and the maximum margin of error respectively (Maystre et al. 1994).

The ELECTRE III method does not allow for compensation, which may occur when using methodologies based on performance indexes, due to the use of the veto threshold. Using this method, an option which shows too poor results in one criterion cannot be ranked in a higher position (Roulet et al. 1999). The model permits a general ordering of alternatives, even when individual pairs of options remain incomparable or when there is insufficient information to distinguish between them (Rogers 2000). Also, the technique is capable of dealing with the use of different units, with quantitative and qualitative information and with aspects that must be maximized and others must be minimized.

This method allows, in an easy and quick way, to outrank construction solutions options according to a set of criteria pre-established and based on criteria weights and thresholds assigned to each one. The criteria, criteria weights and thresholds are selected by the design team according to the objectives and constraints of each project which enable the use of this methodology to a vast set of possibilities (selection of materials, construction solutions, design alternatives, rehabilitation scenarios, etc.), based on different criteria (thermal and acoustic insulation, embodied energy, weight, heating and cooling needs, etc.). This methodology is not specific to a country and can be used in an early stage of the design phase of a new building or of a refurbishment project, when not all the characteristics are defined.

2.3 *Prediction Tools*

The prediction of the building thermal behaviour, related to thermal comfort and energy efficiency, was done using the thermal insulation trough the calculation of the U-value, determined using the publication ITE50 – U-Values of Building Envelope Elements (Pina dos Santos & Matias 2006). All the solutions selected respect the minimum requirements defined in the Portuguese Thermal Regulation (RCCTE 2006).

The acoustic performance of the building elements was characterized using the weighted standardized level difference of the façade ($D_{2m,\, nT,\, W}$), defined in the Portuguese Acoustic Regulation, estimated using the Acoubat Sound Program (RRAE 2008, EN 12354-3 2000). All the solutions selected respect the requirements defined in the Portuguese Acoustic Regulation (RRAE 2008).

The embodied energy was assessed using the Cumulative Energy Demand 1.04 method from the Life Cycle Assessment (LCA) software, SimaPro 7.1.8 (Asif et al 2001, Frischknecht et al. 2003, PRe Consultants BV 2008).

3 RESULTS

3.1 *Criteria, Criteria Weights and Thresholds*

In the study performed, the ELECTRE III method was applied to the evaluation of several alternative solutions for the façade walls on the basis of five criteria: thermal and acoustic insulation, embodied energy, superficial mass and thickness. Table 2 lists the different criteria, thresholds and criteria weights that were selected, by the design team, for this case-study.

The criteria selected to outrank the construction solutions options are related to the most important characteristics of the IEQ, the thermal and acoustic comfort and influence the energy efficiency of the building. These criteria were also selected because it is possible to define them in a non subjective way, it is possible to predict them in an early stage of the design phase, they are under the designer scope and they are the issues that are also the most valued by the users of the buildings. The minimum thermal and acoustic insulation values are also defined in the Portuguese thermal and acoustic regulations and are mandatory (RCCTE 2006, RRAE 2008).

Table 2. Criteria, criteria weighting and thresholds (criteria to: ↓ - minimize; ↑ - maximize).

Criteria	Units		Criteria Weight	Threshold		
				Preference	Indifference	Veto
Thermal Insulation (U-Value)	$W/(m^{2o}C)$	↓	25	0.30	0.10	0.60
Acoustic Insulation ($D_{2m, nT, W}$)	dB	↑	25	5	2	10
Embodied Energy (EE)	MJ/m^2	↓	20	200	40	400
Superficial Mass (Msi)	kg/m^2	↑	20	50	10	100
Thickness	cm	↓	10	15	3	30

The embodied energy, the superficial mass and the thickness of the construction solution were also selected. The embodied energy is considered to account the environmental impact of the construction solution, as this is nowadays a concern of the building sector. The superficial mass is considered to account the impact of the construction solution in the thermal inertia of the building, as this is essential to the correct behaviour of the building. The thickness of the solutions was selected as it influences the useful area and is an important factor, valued by the designer.

The U-Value, the embodied energy and the thickness of the construction solution are criteria to be minimized to improve the thermal comfort conditions, energy efficiency and environmental impact and to increase the useful area available. The Façade acoustic insulation, $D_{2m, nT, W}$, and the superficial mass are criteria that should be maximized, to improve the acoustic comfort and the thermal inertia of the building.

As the definition of criteria weights and thresholds must take into account the objectives and constraints of the project and capture the points of view of the decision makers, to select them, a sensitivity analysis was performed and the visualization of the outcome impacts was assessed.

The criteria weights were defined taking into account the relative importance of each one of the criteria. The criteria weighting established for the thermal and acoustic insulation criteria, associated to the thermal and acoustic comfort, were defined according to the relative importance of each one to the occupants based on studies performed in Portugal and according to literature (Monteiro Silva 2009, Rohles et al. 1987, Kim et al. 2005). These studies showed that the thermal and acoustic comfort are the most valued criteria. The embodied energy, superficial mass and thickness of the solutions are essentially a concern of the designer.

The thresholds were defined according to the criteria characteristics, for example a 2 dB difference is the threshold at which human beings can perceive differences in noise levels and 5 dB is the noise difference at which clear preference can be expressed for one option over another (Rogers & Bruen 1998).

3.2 *Refurbishment's Construction Solutions*

The first step of the refurbishment process was the replacement of the existing windows and roller shutters by windows with double pane glass with aluminium frame with thermal break (U_w = 2.50 $W/(m^{2o}C)$) and insulated roller shutters (considering the thermal resistance of the window, during daytime and the thermal resistance of the window and of the roller shutter during the night-time, U_{wdn} = 2.00 $W/(m^{2o}C)$). The window frame selected has adjustable air inlets to ensure an adequate air change rate and improve the indoor air quality. Additionally 20 cm of mineral wool were placed in the roof (U = 0.21 $W/(m^{2o}C)$) to improve its thermal performance.

The refurbishment construction solutions selected (shown in Figure 2 and listed in Table 3) cover the solutions most used in Portugal (External Thermal Insulation Composite Systems, ETICS, ventilated wall, insulation and plasterboard or hollow brick panes). The study was done considering three insulation materials (expanded polystyrene, EPS, expanded extruded polystyrene, XPS, and mineral wool, MW).

In Table 3 are also listed the cost of the refurbishment solutions for the façade wall. The costs include the materials, execution and 10 years of maintenance.

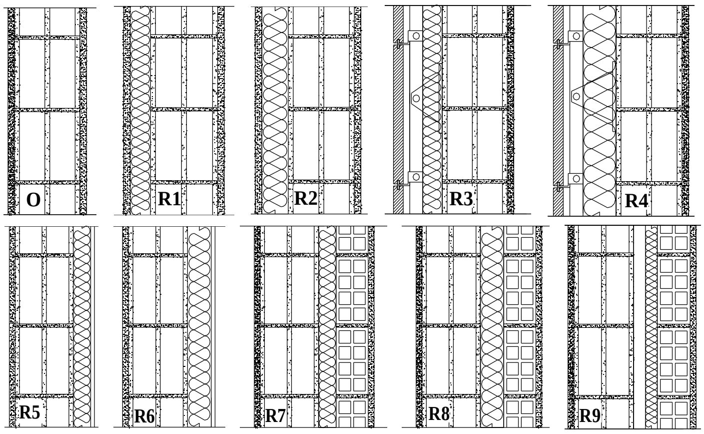

Figure 2. Vertical cross-section of the existing (O) and rehabilitation construction solutions of the façade walls (Ri)

Table 3. Construction solutions studied for the façade (as represented in Figure 2).

Option	Wall	U-Value [W/(m²ºC)]	Cost [€/m²]
O	Hollow concrete block (20 cm)	1.90	-
R1	Hollow concrete block wall (20 cm) and ETICS system with 6 cm of EPS	0.49	58
R2	Hollow concrete block wall (20 cm) and ETICS system with 8 cm of EPS	0.40	71
R3	Hollow concrete block wall (20 cm) and ventilated wall with stone (1 cm) and 6 cm of XPS	0.53	160
R4	Hollow concrete block wall (20 cm) and ventilated wall with stone (1 cm) and 8 cm of XPS	0.44	200
R5	Hollow concrete block wall (20 cm), MW (6 cm) and plasterboard (1.3 cm)	0.73	34
R6	Hollow concrete block wall (20 cm), MW (8 cm) and plasterboard (1.3 cm)	0.64	38
R7	Hollow concrete block wall (20 cm), MW (6 cm) and hollow brick (11 cm)	0.45	15
R8	Hollow concrete block wall (20 cm), MW (8 cm) and hollow brick (11 cm)	0.36	20
R9	Hollow concrete block wall (20 cm), air gap (2 cm), MW (6 cm) and hollow brick (11 cm)	0.42	22

* EPS – expanded polystyrene; XPS – expanded extruded polystyrene; MW – mineral wool.

Table 4 lists the results of the prediction of the façade walls behaviour according to the five criteria selected to outrank the design alternatives. The U-Values are weighted averaged values taking into account the roller shutter box, the opaque and the glazing part of the façade.

Table 4. Criteria for the different design alternatives studied for the façade.

Options	U-Value (weighted averaged values) [W/(m²ºC)]	$D_{2m, nT, W}$ [dB]	EE [Mj/m²]	Msi [kg/m²]	Thickness [cm]
O	2.64	30	0	150	24.0
R1	0.81	33	190	150	32.0
R2	0.74	33	231	150	34.0
R3	0.84	35	1715	150	37.0
R4	0.77	36	1770	150	39.0
R5	0.98	35	195	15	32.3
R6	0.90	36	237	15	34.3
R7	0.77	37	232	140	43.0
R8	0.70	38	275	140	45.0
R9	0.75	39	276	140	45.0

The credibility degree matrix and the results of the outranking using ELECTRE III method are presented in Table 5. The credibility degree matrix gives a quantitative measure to the force of the statement “a outranks b” or “a is at least as good as b”. Number 1 indicates the full truthfulness of the assertion and 0 indicates that the assertion is false.

The ranking of the alternatives can then be determined based on the credibility degree matrix through a distillation procedure, where the alternatives are located firstly following their qualification going from the best to the worse one and then inversely, from the worse to the best one, defining two pre-ranks. Finally, the final ranking is achieved by using the results of these two pre-ranks.

Table 5 shows that the best refurbishment options are the ones with the creation of double pane wall with the construction of an 11 cm brick pane, options R7, R8 and R9. The worst ranked solutions are the ventilated walls and double walls with plasterboards, options R3, R5, R4 and R6.

Option R7 (construction of a 11cm brick pane with 6 cm of MW) is ranked as the best action and is “at least as good as” options R8 and R9 in all criteria, as the number 1 in columns 10 and 11 indicates. This refurbishment solution has one of the lower U-Value, the highest acoustic insulation, has the fourth lower embodied energy and is one of the solutions with the higher superficial mass but is also one of the thicker solutions.

Solutions R8 (construction of an 11cm brick pane with 8 cm of MW), with the lower U-Value, the second highest acoustic insulation and superficial mass and one of the lower embodied energy was ranked second.

These solutions (R7, R8 and R9) are widely used in Portugal and their execution costs (Table 2), are also the lowest.

Table 5. Credibility degrees matrix for the alternative solutions selected for the façade walls.

Options	O	R1	R2	R3	R4	R5	R6	R7	R8	R9	Non-Dom A	m(A)	Ranking Options
O	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	O	0.23	R7
R1	0.77	-	1.00	1.00	0.92	1.00	0.92	0.83	0.74	0.75	R1	0.88	R8
R2	0.74	1.00	-	1.00	0.92	1.00	0.92	0.83	0.75	0.75	R2	0.82	R9
R3	0.00	0.00	0.00	-	1.00	0.00	0.00	0.00	0.00	0.00	R3	0.00	R1
R4	0.00	0.00	0.00	0.98	-	0.00	0.00	0.00	0.00	0.00	R4	0.01	R2
R5	0.00	0.00	0.00	0.00	0.00	-	1.00	0.00	0.00	0.00	R5	0.00	O
R6	0.00	0.00	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	R6	0.05	R6
R7	0.70	0.93	0.95	0.97	0.99	0.94	0.95	-	1.00	1.00	R7	1.00	R4
R8	0.70	0.86	0.93	0.96	0.97	0.87	0.94	1.00	-	1.00	R8	1.00	R5, R3
R9	0.70	0.86	0.93	0.96	0.97	0.87	0.94	0.99	1.00	-	R9	1.00	

The ventilated wall with 6cm of XPS, option R3 (with the lowest U-value but with the higher embodied energy), and the double wall with 6 cm of MW and a plaster board, option R5 (with the lower thermal mass and one of the thinner solutions), both with the same acoustic insulation, were the last ranked options.

Due to their high embodied energy (R3 and R4) and low superficial mass (R5 and R6) are ranked after the existing wall.

The ventilated walls are also the most expensive refurbishment solutions (more than 10 times the cost of the construction of a second brick pane) making them unattractive options for the refurbishment of buildings.

4 CONCLUSION

Throughout the multi-criteria analysis performed, it was possible to verify that the construction of a second hollow brick pane (with insulation), with lower U-value and embodied energy and higher acoustic insulation and superficial mass were ranked the best rehabilitation options. These solutions are the thicker ones and, as the ones with plasterboards, will reduce the building’s useful area and it will be necessary to redo the installations that might exist in the wall.

The last ranked options are the ventilated wall with 6cm of XPS (with the lowest U-value but with the higher embodied energy), and the double wall with 6 cm of MW and a plasterboard (with the lower thermal mass and one of the thinner solutions), both with the same acoustic insulation.

The placement of the insulation inside the existing wall, R5 to R9 refurbishment options, leads to the necessity of redoing the coupling with windows and door frames and lead to more inconvenient during the refurbishment works.

The placement of the insulation outside the existing walls is not always possible, in multifamily buildings and when the buildings are in contact with the streets or public spaces and it’s not possible to expand the wall outwards.

The case study here presented allows a robust analysis of the refurbishment options for the building’s façade as it comprises a broad study of each alternative through a detailed analysis of the main factors that affect the IEQ, based on the thermal and acoustic insulation levels and the embodied energy of the construction solutions.

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Which architecture has proven to be successfully climate responsive?Learning from traditional architecture by looking at strategies for resource efficient and climate responsive constructions

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ABSTRACT: There is a lot we can learn by looking at traditional architecture. Our ancestors found many solutions for sustainable buildings regarding energy and resource efficiency. Especially strategies to avoid overheating in summer are worth looking at, because people found other “zero energy solutions” before there was the technical solution of A/C. Many surveys show an analysis of climate adapted architecture but in most cases they do not make a statement about how to use this knowledge today. (Asquith 2006)
As part of a PhD Thesis the strategies for passive measures at traditionally built houses in the upper town of Thessaloniki in northern Greece are looked at. The style of these houses is named “Makedonian Architecture” and can be found in northern Greece as well as in neighboring regions. It is well known that these houses have a good thermal comfort for the people living there. To understand the strategies leading to this comfort the concepts of the houses have been investigated with simulation software: the natural ventilation as a very important factor, the building materials and the orientation and shading devices. The data for the simulation of the natural ventilation have been taken from measurements in the wind tunnel of the University of Hamburg. Series of measurements have been made within different settings of the urban surrounding.
For this paper it is intended to focus on the thermal comfort strategies to avoid overheating in the summer leading to the basis of design strategies to be defined.

1 INTRODUCTION

Residential buildings in the Balkan area have adapted to their specific regional conditions and can show strategies to avoid overheating in the summer. Within a PhD research this knowledge is recorded and analyzed. As an example of Balkan architecture the survey is looking at the buildings in the upper town of Thessaloniki. This building style developed over a long period in the Ottoman Empire and spread throughout the Balkan region. (Cerasi 2004, Anastasiadisn.d.)

The houses in the upper town have been built by Turkish families in the 19th century and show a similar structure throughout the area (Fig. 1). The ground floor structures are made of massive natural stone masonry, often green schist stones, with small openings. The walls are approx. 70 cm thick. One or two upper floors are built as a light structure, made of timber framework and brick masonry with plaster on both sides. The walls are approx. 15 cm thick and are painted in light colors. On the exterior side there is often an additional layer of lime plaster. The side hung windows have shutters as shading devices with movable slats to be adjusted to the sun. These elements allow to fully open the shading devices in contrary to the typical windows of the Turkish ottoman house with a fixed part in the upper half of the window and a sliding element on the bottom.The roofs are covered with tiles and have an overhang of about 60 cm. All houses have at least one articulated eave overhanging the street. The streets are narrow and curvy, ascending towards the hilltop. The buildings are situated within an urban context of a densely built surrounding on a slope, facing the sea.

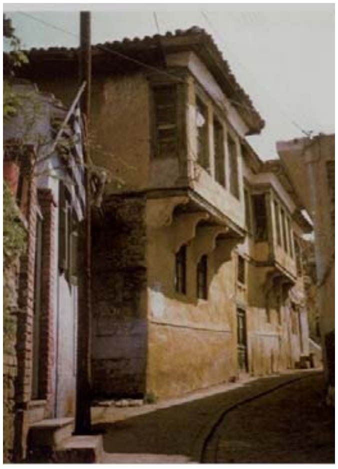

Figure 1.Building in Epimenidou Street, Thessaloniki, picture by: Michael Nomikos

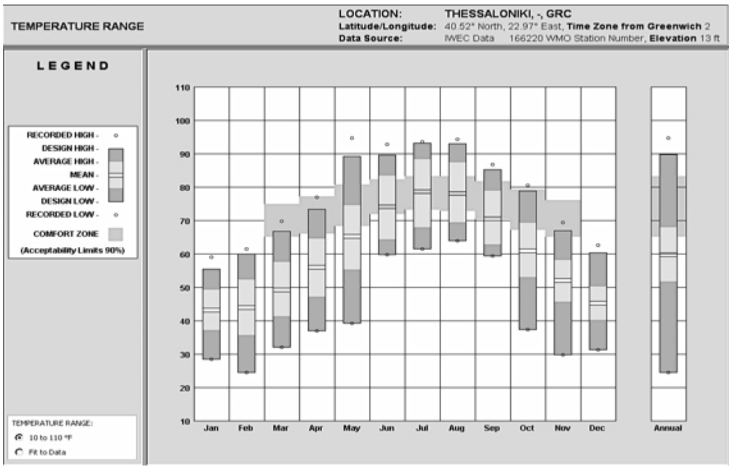

Figure 2.Climate chart of Thessaloniki, temperature in °C, adaptive Comfort Model, ASHRAE Standard 55-2004, Climate Consultant 5.4

1.1 *Climate*

The climate in northern Greece can be described as cold in the winter with a relative humidity of up to 80% and warm and dry in the summer as shown in Fig. 2. From May to September the temperature will often rise above the comfort level. The high temperatures in June, July and August will lead to overheating inside buildings without adaptation to the climate or energy demanding air conditioning.

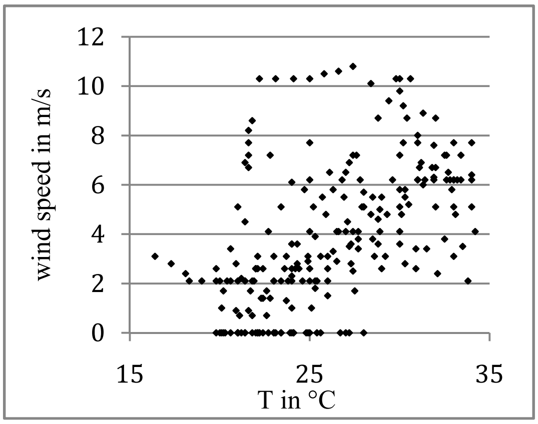

Figure 3. Wind velocity in relation to air temperature in Thessaloniki, 1st to 10th of July

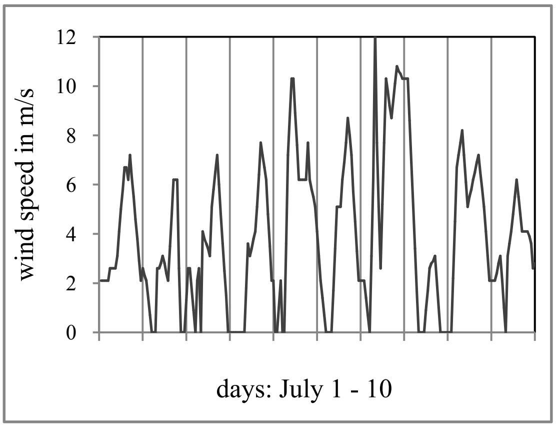

Figure 4. Wind velocity profile, both charts based on climate data from Energy Plus

In summer months on warm days the prevailing wind in the daytime will have a velocity of about 3-7 m/s (Fig. 3). In the calculations of the natural ventilation 5 m/s is taken as a typical situation and 2 m/s as bad conditions. On a typical day the wind will blow from northern directions in the morning, changing to western and southern directions in the afternoon. In the night there will often be no wind at all or weak wind from eastern directions (Fig. 4). A climate responsive building will make an advantage of the cooling effects of natural ventilation to prevent overheating in this season.

1.2 *Comfort*

The psychometric chart shows clearly that there is the need to influence the temperatures in summer (June, July, August) because the number of hours an occupants of a space is thermally comfortable are less than 50 % (ASHRAE Standard 55-2004 Comfort Model). This result is based on the Energy Plus climate database which was also used for the simulations.

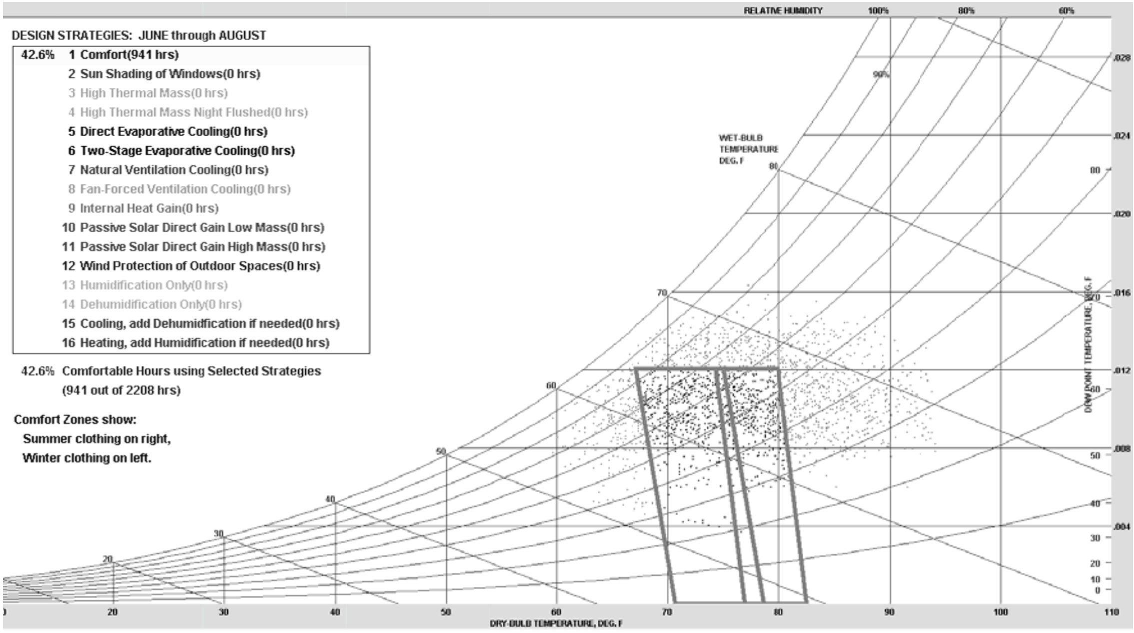

Figure 5.Psychometric chart, Thessaloniki for June, July and August, Climate Consultant 5.4

2 CALCULATIONS AND SIMULATIONS

The strategies leading to a climate adapted building are investigated through calculations of the air exchange rate, material testing in the HCU laboratory and simulations with software tools. The simulations and tests in the wind tunnel have been made for a reference building with the typical features, proportions and building materials of a traditional building in the upper town.

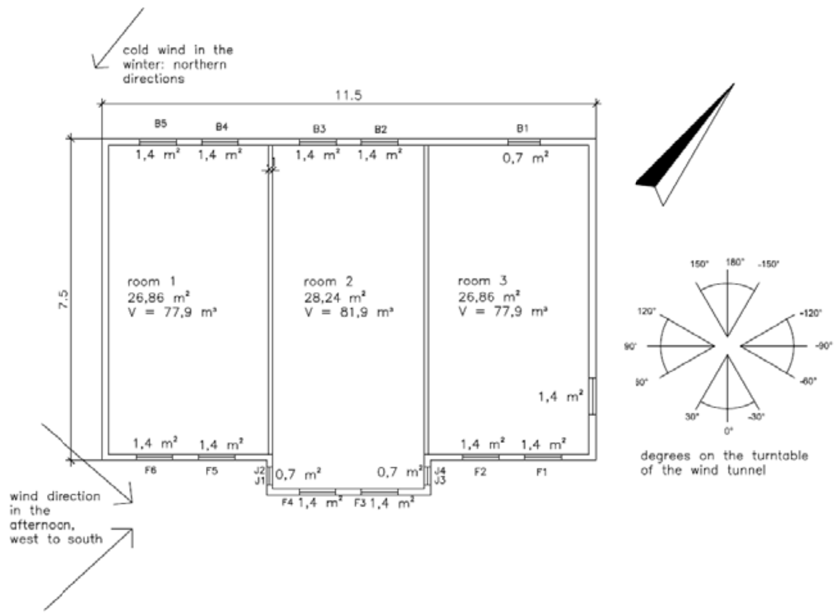

Figure 6.Floor plan 1ststorey of the reference building in optimized orientation to prevailing wind

2.1*Natural ventilation*

The ventilation of the rooms is a very important factor concerning the temperature and the air quality. Ventilation in the houses in the upper town of Thessaloniki is provided through the windows. The ground floor with the massive structure has small openings to keep the warm air in the winter. The upper floor(s) have wide openings to provide as much ventilation as possible to avoid overheating in the summer.

The openings of the upper floor have hinged windows with wooden slat blinds with adjustable blades on the outside for shading. Turning the blades horizontal gives the user the possibility of shading without blocking the ventilation of the room when the sun is high and also the opportunity of night ventilation giving protection against burglary.

2.1.1 *Simulation of indoor temperatures depending on the air exchange rate*

Simulations with PRIMERO 1.1show for the reference building that a minimum air exchange rate to avoid overheating should be at least 3/h during day and night. Figure 7 demonstrates the hours a temperature in the room is exceeded.

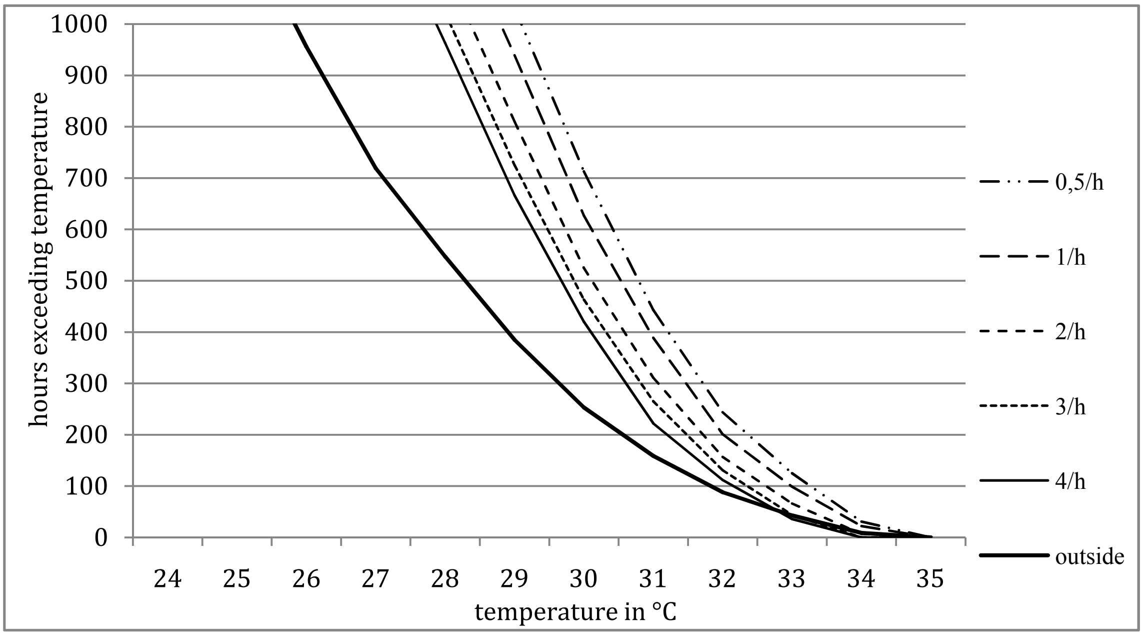

Figure 7. Hours exceeding a temperature inside the rooms according to the ventilation rate, simulation with PRIMERO 1.1

To calculate the surface pressure difference needed for an air exchange rate of 3/h equation 1 from the BS 5925-1991 was taken

$$m_W = c_d \, A_W v_r \, (\Delta c_p)^{0,5} \qquad (1)$$

wherem_W = ventilation rate; c_d = coefficient (0,65 for a rectangular opening); A_W = effective window area, $1/\ A_W^2 = 1\ /\ (A_1 + A_2)^2 + 1\ /\ (A_3 + A_4)^2$ with $A_1 - A_4$ being the window opening area; v_r = reference wind velocity; and Δc_p = mean surface pressure difference.

Calculation of the reference wind velocity v_r with equation 2 from BS 5925-1991

$$v_r = K\, z^a v_f \qquad (2)$$

whereKand a = factors to determining different wind speed (for city areas K = 0,21 and a = 0,33); z = building height; and free wind velocityv_f.BS 5925 – 1991

To achieve a minimum air exchange rate of 3/h with cross ventilation a pressure difference Δcp of less than 0,05 is sufficient with two facing windows with openings of about 1,4 m² each (Table 1) and a low wind speed of 2 m/s.

Table 1. Calculation of the air exchange rate with cross ventilation in a room of 80 m³ in the upper floor of the reference building according to the calculation method of BS 5925-1991

Δc_p	v_f in m/s	A_W (effective window area)	Air exchange rate
0,1	5	1,32	23
0,1	2	1,32	9,5
0,1	5	1,0	18
0,1	2	1,0	7
0,05	5	1,0	13
0,05	2	1,0	5

A_W = 1,32: two windows, e.g. F6/F5 – B5/B4 on each side of the room opened, shutters closed
A_W = 1,0: two facing windows opened, e.g. F6 – B5

A simulation done with EnviMet run for the 23rd of June with the climate database of Energy Plus matches the result. With vf of about 5 m/s in the height of the upper floor of the buildings the velocity is still about 2 m/s (Fig. 9). The reference velocity vr for the reference building is calculated with 2,06 m/s for vf being 5 m/s.

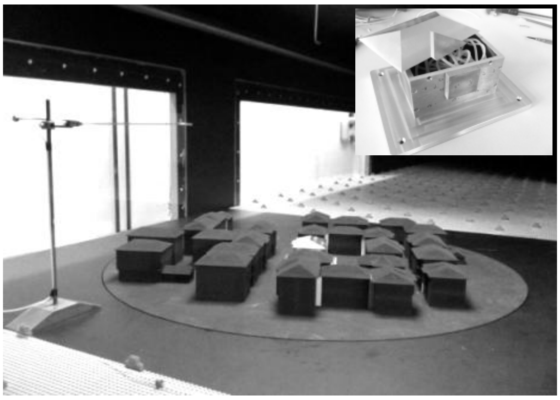

Figure 8. Model of reference building and setting in the wind tunnel

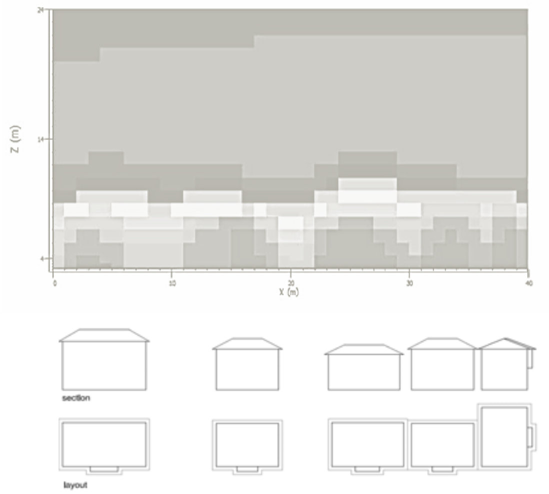

Figure 9.Wind velocity: results from EnviMet simulation

2.1.2 *Wind tunnel experiments*

To learn about the ventilation potential measurements in the wind tunnel of the University of Hamburg have been made. The reference buildingwas tested in a boundary layer wind tunnel within different urban surroundings typical for the upper town of Thessaloniki. One reference building A made of aluminium with a projecting eave was equipped with 22 sensors, located where the windows would be and set in the middle of a turntable (Fig. 8). Another building B was made in exactly the same way, but without the projection. The surrounding buildings were made of MDF. For each 11 different scenarios of the urban surrounding and one reference measurement without surrounding buildings 12 measurements were made moving the turntable 30° each time (Fig. 6 and 8). To learn about the impact of the projecting eave three settings were measured with building A and B. The test and the runs were carried out as described in the VDI 3783 Blatt 12.

According to the wind tunnel experiment the pressure difference Δcp of 0,05 is present most of the time (Table 2). The measured values in the wind tunnel do not exactly match the values from the BS 5925 – 1991 and the tables of Dietze (1987) but stay in the same range. In this case the values given in tables could have been taken for an estimation but the wind tunnel experiments give the more precise information.

Analyzing the pressure difference for different scenarios it shows the following results: There is a potential for cross ventilation even in dense surroundings depending on the orientation of the building. The projection into the street has two positive effects: in windward directions it enhances the ventilation potential for room 2, in leeward directions it lowers the pressure difference for the whole building which is a positive effect in winter time to protect against cold wind.

Table 2.Δc_pvalues measured in the wind tunnelbetween two opposite windows for case A (with eave) and B(without eave) in a dense urban surrounding

		Δc_p											
		Wind direction in the wind tunnel											
Case	Room	-150°	-120°	-90°	-60°	-30°	0°	30°	60°	90°	120°	150°	180°
A		0,49	0,19	0,12	0,00	0,18	0,00	0,00	0,27	0,44	0,34	0,02	0,08
B	1	0,26	0,35	0,26	0,19	0,19	0,03	0,00	0,28	0,56	0,29	0,19	0,19
A		0,00	0,12	0,14	0,26	0,20	0,26	0,23	0,38	0,48	0,41	0,21	0,11
B	2	0,12	0,19	0,13	0,20	0,17	0,20	0,27	0,20	0,38	0,20	0,21	0,20
A		0,00	0,06	0,15	0,12	0,13	0,06	0,23	0,10	0,14	0,00	0,13	0,21
B	3	0,17	0,13	0,12	0,24	0,16	0,06	0,30	0,11	0,19	0,12	0,22	0,33

2.2 *Building materials*

The materials typically used for the buildings in the upper town have been analyzed to calculate an exact u-value of the walls. Tests in an x-ray diffractometer supported the assumption of the plaster being a lime mortar with mixed aggregates. Also the density of the bricks and the natural stones was measured in the HCU materials laboratory. Is was assumed for the reference building that the ceiling towards the attic has been insulated in the traditional buildings because this is a very simple method to avoid overheating in the summer as well as lower the heating demand in the winter.

Figure 10 shows the differences in the indoor summer temperatures for the reference building with an air exchange rate of 3/h and different scenarios for changes in the materials. The traditional building has a very good performance already, which could be improved by modern insulation materials on the exterior façade. This would have the effect of lower temperatures inside the building when the outside temperature exceeds 28°C.

An interior insulation would have a negative effect and worsen the performance.

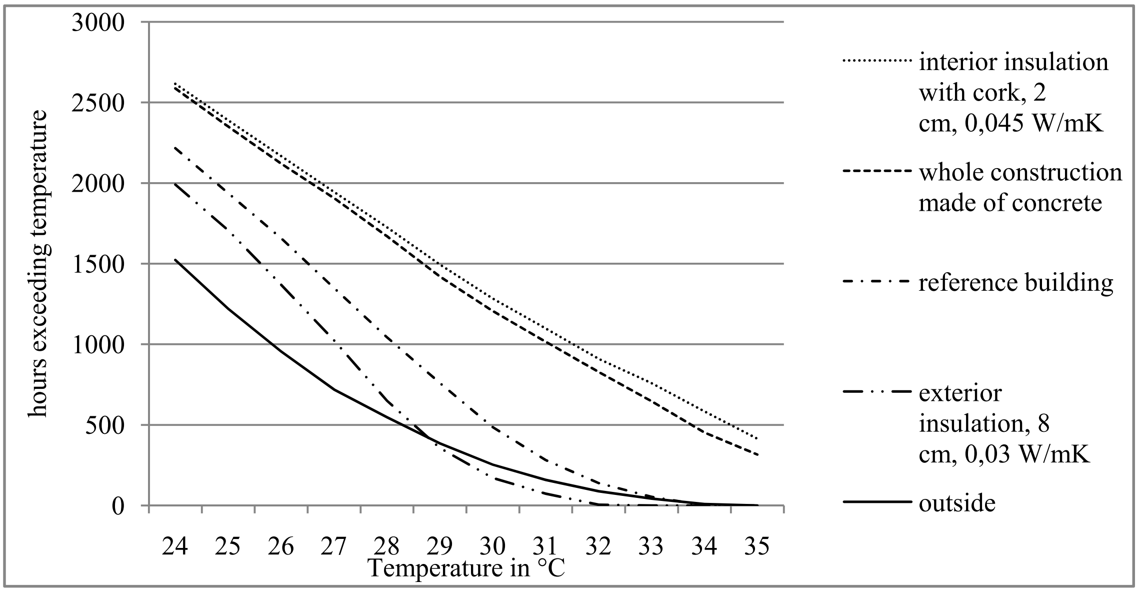

Figure 10. Hours exceeding a temperature inside the rooms according to the building materials, simulation with PRIMERO 1.1

Building the same building shape with concrete as a typical modern material it can be shown that it extremely overheats in summer (Fig. 10 and 11). The surface temperature of the concrete rises high above the outside temperature after the maximum temperature of a day is reached.

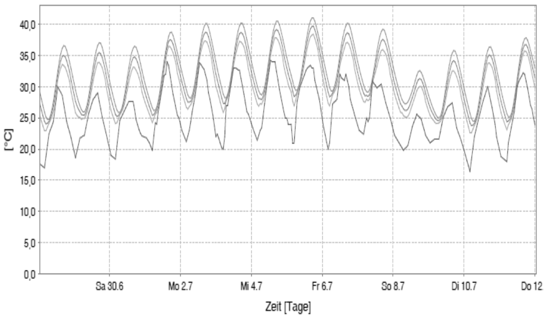

Figure 11.Outside temperature (lower graph) And interior surface/air/operative temperature (upper graphs) of the concrete construction

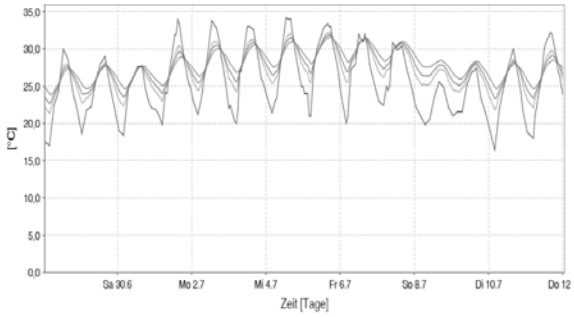

Figure 12. Outside temperature and interior surface/air/operative temperature (three graphs) of the traditional building with exterior insulation

2.3 *Shading*

The shading devices on the building are the shutters on the windows, the overhang of the roof and the projecting eave, shading the façade and some windows.

The effect of the orientation of the building regarding the course of the sun seems relatively low. This results of a box shaped building form and the roof overhangs similar on all sides, shading the windows and façade of the upper floor.

The simulation shows that the temperatures inside the rooms will be lowest when the shutters are always closed when the sunshines. Replacing the shutters by exterior roller blindshas a significantly negative effect to the room temperature, including into the simulation the blocking of the natural ventilation. The effect of metallic coated interior roller blinds is similar because the windows cannot be fully opened but there is more ventilation possible because the windows can still be tilted (Figure 13).

The simulation does not include the materials for the shading devices.

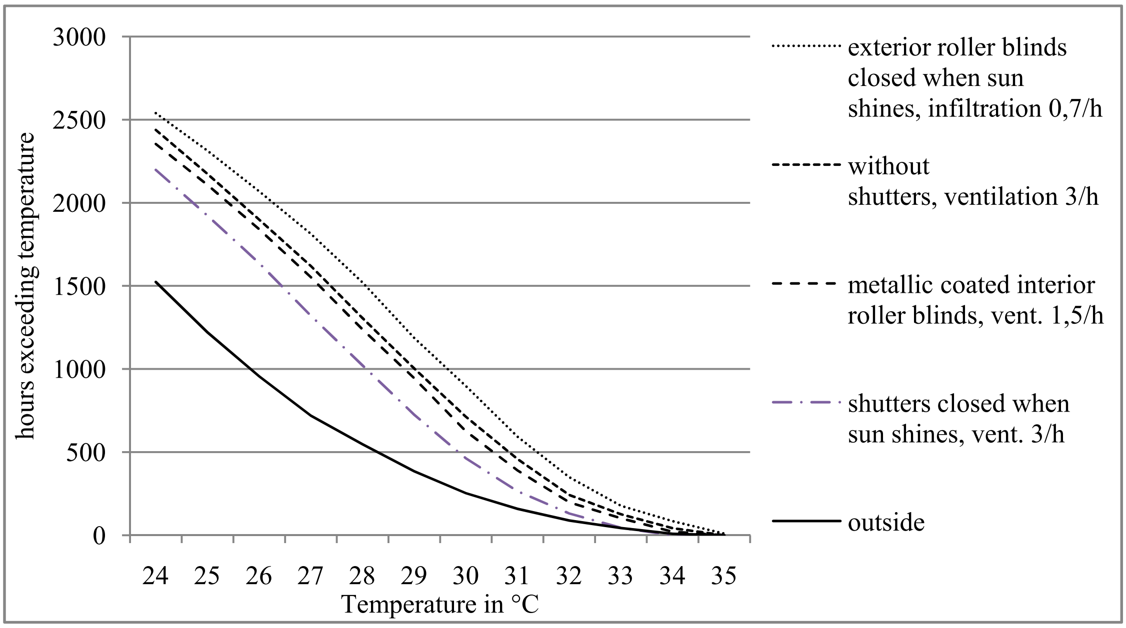

Figure 13. Hours exceeding a temperature inside the rooms according to the shading devices, simulation with PRIMERO 1.1

3 RESULTS

The results of the wind tunnel experiments, calculations and simulation are: assuming a user who knows how to make use of natural ventilation and shading devices a traditional residential buildingwill not overheat in a typical summer. The natural ventilation provided by wind through the windows and the shading devices allowing ventilation and shading at the same time are sufficient to keep the temperatures inside the rooms acceptable without any air conditioning.
The building materials have been proved to be climate responsive.

An important aspect is the need of combining different strategies. Withoutcross ventilation to avoid overheating and therefore a reduction of the air exchange rate it will lead to overheating in summer for a high number of days.

The efficient ventilation has to be combined with the shutters on the windows. The solar heat gain in summer will lead to high temperatures inside the building without the shading on the windows. The shutters also have the function of protection against burglary to make night ventilation possible. Typical roller blinds have a negative effect.

The third factor investigated has been the building materials. The construction of the upper floors, consisting of timber frames with brick masonry proved to have positive effects for the comfort inside the building. Other construction materials will not lead to the same results.Modern building materials like concrete will cause inacceptable overheating of the rooms.

4 CONCLUSION

The results of this research will be the basis for planning guidelines for the renovation of modern and not climate responsive houses in Greece built in the 20th century when this knowledge was not used any more. It could be shown by looking at the traditional architecture that it is possible to design a residential building, which does not overheat in summer with passive measures. The idea is not a “back to the old” but a translation of the strategies into our today needs. This could drastically reduce the need for air conditioning in residential buildings.

A questionnaire done in 2012 demonstrated that many people do not know about the use of shading devices and ventilation to achieve thermal comfort. Therefore the guidelines will need to show a way to influence the user behavior as well.

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Research into Natural Bio-Based Insulation for Mainstream Construction

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ABSTRACT: This paper summarises aspects of research carried out by The BioComposites Centre over the last ten years on a number of different projects in the field of bio-based insulation. Areas covered include issues around raw material processing and manufacturing, 'improving' properties, fire retardant treatments and fire performance, determination of steady state thermal performance for the declaration of performance criteria and aspects of in-situ unsteady statebehaviour. Case studies illustrating the buffering effect of natural bio-based insulation will be reviewed and results of a test to determine the adsorption of formaldehyde by wool fibres discussed. Future research including a research programme funded under FP7 entitled "Safe, energy-efficient and affordable new eco-innovative materials for building envelopes and/or partitions to provide a healthier indoor environment" are highlighted and what The BioComposites Centre will be doing to try and improve the performance of these insulation materials.

1 EARLY RESEARCH

1.1 *Initial work and aims*

Much of the early work carried out at The BioComposites Centre (BC) when it was first established in 1989 focused on 1) substituting agricultural crops into various wood based industries such as panel products and the pulp and paper industry, 2) looking for new products that could be made from agricultural crops 3) chemical modification of bio-based fibres to improve properties and 4) extraction of a range of chemicals from bio-based sources of material. This work was funded by a variety of research contracts both publically and privately funded with durations varying from short contracts lasting a few weeks to projects spanning many years. Much of the publically funded research was used to inform policy makers and little continuity between projects was and still remains a frustration. Lack of opportunity to develop ideas commercially within The BioComposites Centre led to the formation of a spin out company, JB Plant Fibre, by James Bolton and Gary Newman in the mid-1990s. The company installed machinery for processing long fibres into needled mats and this started a long association with Gary Newman that continues to this day into research into bio-based materials.

1.2 *Farm trials*

On-farm and experimental trials of growing hemp and flax (Henfaes Flax and Hemp Project) led to a number of valuable findings, one of the most surprising in the first year being the reported variation in extracted fibre yield from 400 – 1100kg/ha between different farms. Improvements to agronomy, use of desiccation techniques to ret the crops while still standing and specialised harvesting equipment led to significant improvements in crop yield, quality of fibre, consistency and, of prime importance to the industrial partner, the cleanliness of the bales delivered to the processing factory. Despite the success in terms of improvements to fibre quality and product development, hemp and flax growing in the area virtually stopped overnight, mainly dueto the removal of European growing subsidies.

A key draw back identified from this hemp/flax growing was the lack of end products and markets sothat crops could be grown independent of the need for subsidies. A market review carried out by BC identified insulation as an unexploited potential market forthese fibres. Thus followed a series of projects which continue to this day looking at various issues related to bio-based insulation materials. The main objectives of thepreliminary work were the expansion and acceleration of the market for domestic insulation products manufactured from UK grown flax fibre by the measurement and improvement of product performance.In turn, product specifications were defined and the public profile of natural fibre insulation was increased. It was reasoned that by increasing the market share for these products, at the time imported from France, it would help to enable processing to be carried out within the UK by the creation of a demand for UK grown flax to supply the processing facility/facilities. Prior to this time, sales of insulation were sold basically on thermal performance and cost; however, feedback from tradeshows and customers indicated that increasingly end users were demanding additional performance benefits and the two main areas of concern at the time were fire and acoustic performance.

2 PERFORMANCE IMPROVEMENTS

2.1 *Acoustic properties*

At the time no performance data existed on acoustic properties of Isonat, a flax fibre insulation imported into the UK by Plant Fibre Technology. End users had little confidence that this material would perform sufficiently well to comply with recently introduced legislation in UK Building Regulations, referred to as “Part E” (UK Gov, 2010). These regulations were introduced by the Government, "as part of an overall strategy to improve quality of life".

The results of acoustic testing are reported in Table 1. They show that this insulation was easily capable of surpassing the requirements of Part E of the Building Regulations and the concern of compliance was no longer an issue. The focus then turned on other areas. Having satisfied the end users with regards to the dual thermal and acoustic functionality of bio-based insulation products, the question was then raised as to what effect installing this material into a partition wall would have on fire resistance.

2.2 *Fire resistance*

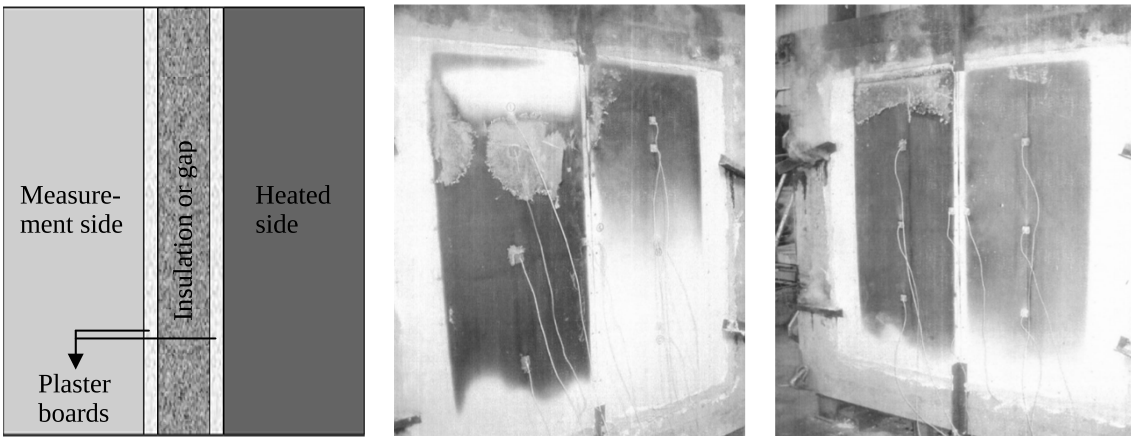
Fire resistance is the ability of a structural element to sustain, for a given period of time, the performance of its structural duty while being exposed to the elevated temperatures likely to be encountered in a developed fire. Indicative tests were carried out on three wall build ups with one containing no insulation,one containing glass fibre insulation, and one containing bio-based insulation. Figure 1 shows the construction detail and photos taken during the tests showing positioning of the thermocouples; the tests and the results are shown in Table 2.

This area of concern was partly satisfied but fire performance has been and continues to be a recurring theme through many projects in terms of the level of performance, type, and application method of fire retardants. The conclusion resulting from the testson performance levels was that without some form of treatment bio-based natural fibre insulation would fail to meet Euroclass E classification for fire performance. It was also concluded that this level of performance was sufficient for the product to be used in most domestic applications and, while small improvements were possible, there was no legislative pressure and little market advantage to be gained by doing so. Education of the end user and good quality marketing material to get over these points were thus needed in this area. It was concluded that further work on fire retardants should concentrate on reducing cost and improving environmental credentials. However the application of fire retardant to fibres was and still remains an area where improvements can be made.

Table 1. Results of airborne sound transmission test.

Test number	Description	Test performance R_w (C;Ctr)*	Regulatory requirement R_w
		dB	dB
1	2 x plasterboard each side of twin timber stud, with insulation	59 (-1;-6)	45 New 43 Rebuild
2	2 x plasterboard each side of single timber stud, with insulation	48 (-1;-5)	40
3	1 x plasterboard each side of single timber stud, with insulation	45 (-3;-10)	40
4	2 x plasterboard each side of metal studwork, with insulation	52 (-2;-7)	40
5	1 x plasterboard each side of metal studwork, with insulation	46 (-3;-10)	40
6	1 x plasterboard each side of metal studwork	37 (-2;-6)	40

*C and Ctr are correction factors used for predicting the performance on site as opposed to laboratory build ups.



Cross sectional view of wall construction | Test with hemp insulation | Test with no insulation

Figure 1: Construction details and photos of fire tests.

Table 2.Results of indicative fire resistance testing for three different partition wall build ups.

Type of insulation in wall	Time for initial maximum surface temperature to be exceeded	Time for mean maximum surface temperature to be exceeded
	s	S
No insulation	33	34
Glass fibre insulation	39	40
Natural fibre insulation	41	44

3 PRODUCTION AND OTHER IMPROVEMENTS

3.1 *Fire retardant and binder application*

Some work on improving production methods was started in 2003. Two main areas were identified where improvements could be made to 1) the common method of treatment with fire retardant, which was to dip treat fibres prior to assembly into the product and then spray top and bottom surfaces of the finished insulation, and 2) use of bi-component polyester fibres in air laid bio-insulation to provide the bonding method between fibres, holding them together and maintaining loft. Whilst very effective in terms of performance this polyester fibre reduced the environmental credentials of the product. It was believed that it should be possible to adapt technology, known as 'blowline blending' used within the short fibre, medium density fibreboard industry for application of adhesives, fire retardants and other additives used in treating long bio-based fibres. While the concept was successfully proven and a patent was filed, it was not pursued due to lack of commercial partners at the time. Bi-component polyester fibres remain the standard binder in air-laid long fibre insulation products.Although the market offers a natural bi-component substitute, currently its higher cost precludes it from all but specialised one off orders.

3.2 *Hemp production*

In 2008, attention was given to get hemp insulation finally manufactured in the UK and to address some of the key areas of lack of knowledge surrounding use of bio-based insulation. Integration of the whole supply chain from primary processing, architectural specification, product performance and end users was achieved through a project co-funded by the Technology Strategy Board and titled ‘Energy Efficient Bio-Based Natural Fibre Insulation’. Black Mountain Insulation joinedthe consortium when one of the original partners who had intended to start up manufacturing went into administration;hemp insulation was successfully manufactured by Black Mountain Insulation in the UK and went on sale during the project. Otheraspects of the project were not so clearly beneficial but, in summary, whilst the technology developed did not revolutionised the natural fibre insulation market, there was an incremental improvement in cost reduction, environmental performance and technical performance.

3.3 *Technical findings*

One of the importanttechnical findings of this project has been a better understanding of hygrothermal performance of bio-based insulation materials. Whilst there was much anecdotal evidence for this, little published data existed at the time. A whole body of work carried out by the University of East London in association with the Centre for Alternative Technology has led to the submission of a thesis by EshrarLatif ‘Hygrothermal performance of hemp based thermal insulation in the UK’. It is envisaged that a number of papers will be published in the near future as a result of this body of work. A key finding of the work was that in high levels of relative humidity, the likelihood and frequency of interstitial condensation is higher in stone wool insulation than in hemp insulation, i.e. hemp insulations have a high level of moisture buffering capacity and therefore they have the potential to manage moisture in buildings. Further work on thermal performance of insulation material has been carried out between Black Mountain Insulation and Bangor University through a Knowledge Transfer Partnership (KTP, Programme 008050 - Review, evaluation and improvement of current production processes, and the development of a strategic product improvement programme).

Another key result to have come out of thiswork was the development of a method for measuring the sorption of formaldehyde gas by wool (Curling et al. 2011). Formaldehyde is highly reactive to the protein structure of wool with an affinity to the side chains of amino acids lysine and arginine. This paper reported that few studies were available to show gaseous sorption of formaldehyde by wool; references for chamber studies showing a reduction in the formaldehyde in the air are reported, but these methods do not directly measure the formaldehyde sorption. Work carried out at by BC showed that it is possible to calculate the amount of formaldehyde sorbedby exposing the material to a formaldehyde rich atmosphere followed by reconditioning to a formaldehyde free atmosphere while measuring the weight loss. The method has the advantage of measuring directly the change in fibre weight rather than the change in atmospheric formaldehyde concentration. In a standard water isotherm the change in mass should return to zero at 0% relative humidity (RH); however, if formaldehyde is sorbed then there should be a difference in mass at 0% RH. Figure 2 shows the results of that work.

Repeated sorption/desorption cycles were carried out to determine the maximum that could be sorbed and if it was reversible. Maximum sorption was found to be 4.9% (equating to 49g/kg of wool) with 33% not permanently bound to the fibre. Released formaldehyde is likely to have been physiosorbed, with its release enabled by moisture which opens pores within the wool fibre structure. Further studies are required to understand the full mechanism and effect of possible hydrolysis of sorbed formaldehyde. The difference between single and multiple cycles for an amount of formaldehyde sorbed shows that one cycle is not enough to determine the total sorption possible. Equilibrium was reached between the 5th and 6th cycle.

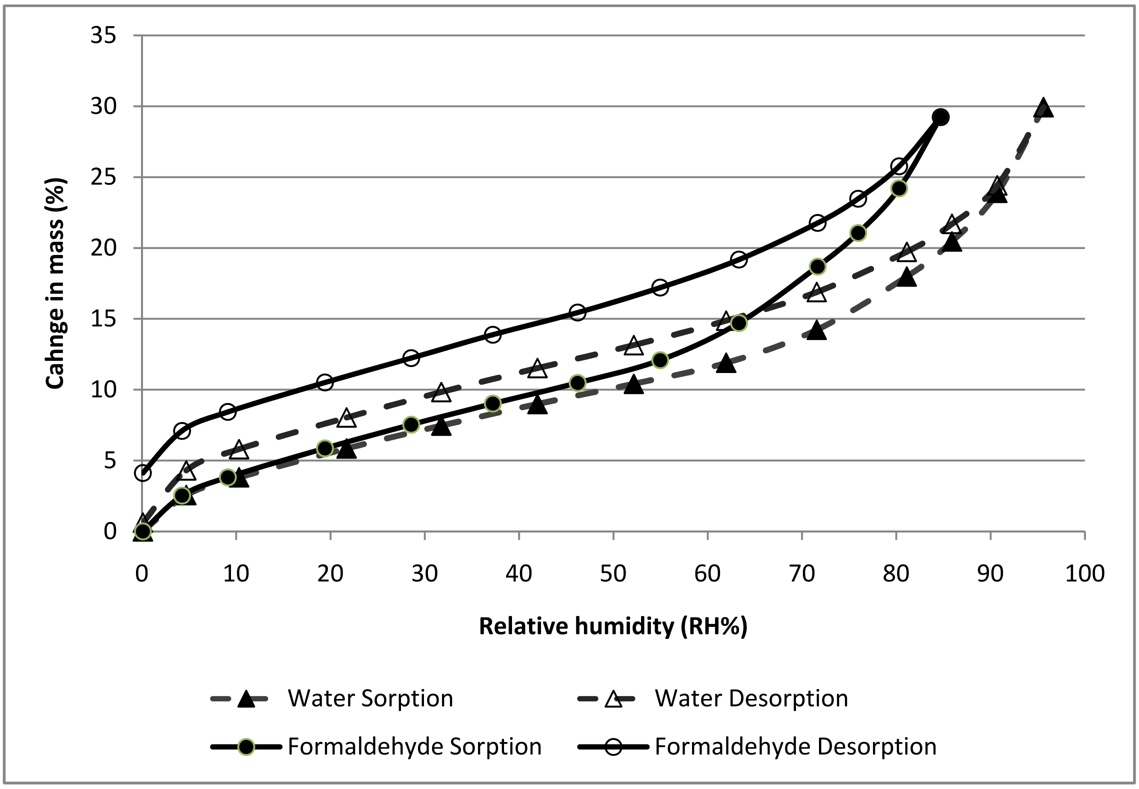


Figure 2. Change in mass of wool fibre during sorption and desorption of water and formaldehyde.

In the practical use of woollen products it is possible that environmental variables and various treatments and finishes of the product could affect the sorption properties of the fibres. Research in this area will be investigated at BC to test the significance of fibre variables and treatments.

Further benefits of the KTPProgramme 008050 between Bangor University and Black Mountain Insulation have been considerable. From the manufacturer's point of view, significant improvements to production methods resulted in reduction in wastage, cost savings and an accelerated cycle of new product development. Benefits for the academic partner have included a greater understanding of the technical and manufacturing environment as well as the opportunity to link technical performance with marketing efforts and the development of new areas for research in behaviour change and consumer psychology.

One area of research activity was an increased understanding of the use of steady state thermal testing using a hot plate method in accordance with BS EN 12667:2001"Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance" (British standard institution, 2001) to determine thermal resistance. This standard test is used to declare thermal performance of products and is required if they are to be put on the market place. There are some issues with this method though, one being that it is a steady state test whereas insulations in use experience a wide range of temperatures and humidities over which they are required to perform. Bio-based materials buffer moisture and require particular handling when using this equipment in order to ensure consistent and reliable results. Work in this areaconsidered variables such as density, temperature range and moisture content during testing. One finding from the work was a noticeable difference between the time required for bio-based insulation to reach thermal equilibrium compared to man-made fibrous insulation, as can be seen in figure 3. This effect is attributed to the difference in thermal mass between the two samples.

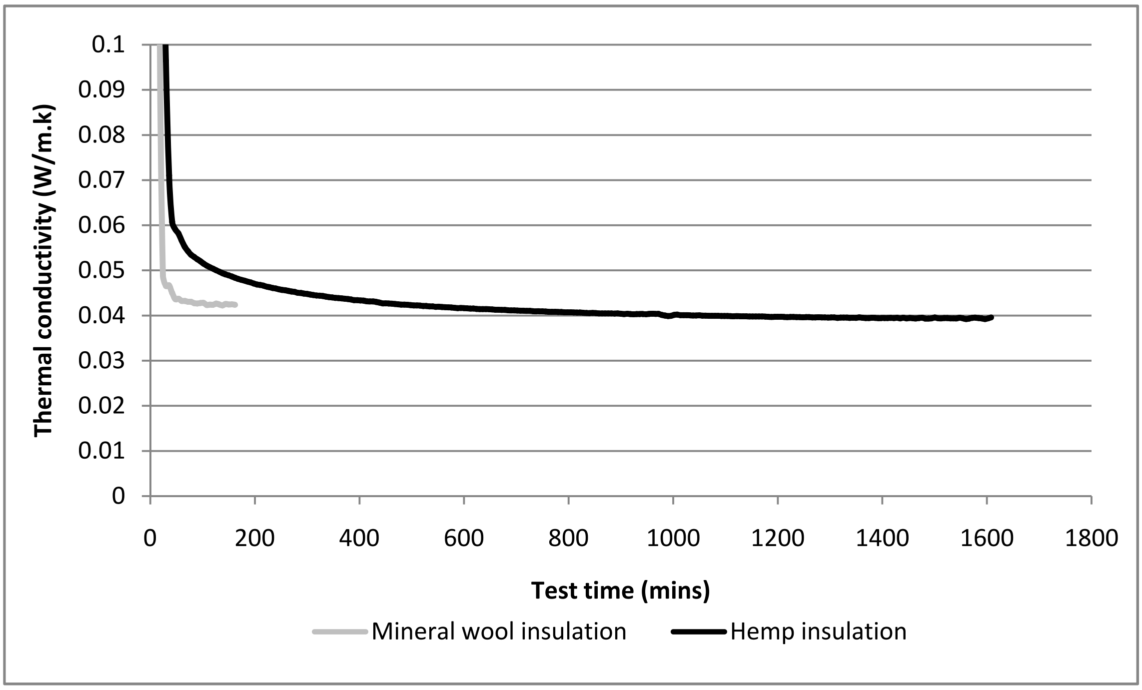


Figure 3: Graphical representation of thermal conductivity results using FOX 600 instrument, calibrated using NIST SRM 1453 expanded polystyrene board (Zarr, 1996). Tests were run between 5 and 15°C. Mineral wool insulation is 600 mm by 600 mm by 100mm dimensions and a density of 11.1 kg/m^3, conditioned to ambient conditions. Hemp insulation consists of 95% hemp fibre and 5% polyester, having 580 mm by 600 mm by 100 mm dimensions and a density of 50.0 kg/m^3, conditioned to ambient conditions.

Thermal mass is the ability of an object, such as insulation material, to retain heat that it has been exposed to. In general, the denser an objectis the more thermal energy it can store, which is later released back when the surrounding temperature drops below the surface temperature of that object. At this point, the thermal energy on the surface is released into the surrounding atmosphere, and the thermal energy within the object flows towards its surface; the process is repeated until the temperature inside the object is constant and equal to the surrounding temperature. Therefore, the release is gradual and in effect creates a temperature buffering mechanism. Heat sources for buildings include ‘free energy’ such as direct sunlight. An object having thermal mass can reduce the need for heating or even remove it altogether. Intelligent designs and new building models such as solar homes take full advantage of this property, and are thus referred to as ‘intentional mass’ (Chiras, 2002, Shaviv et al. 2001). It is noteworthy that other more popular new builds tend to utilise light weight material, leaving insulation as one of the biggest possible contributors to thermal mass.

3.4 *Market development*

One of the recurring themes through all of these projects over many years has been the need to develop the market in the UK for bio-based insulation products. Initially this was seen primarily as a need for better understanding and availability of data related to performance based issues. Whilst these are important the wider context of policy, legislation, standards, certification and the whole ‘sustainability’ issue came more and more into focus. Good technical performance on its own was not translating into market development. Partly as a result of this and through increased contact of project partners with other manufactures of a range of ‘eco’ products in the UK, the Alliance for Sustainable Building Products (ASBP 2013) was founded with the specific aim of “accelerating the transition to a low carbon built environment” by championing the increased understanding and use of sustainable building products. Helping companies to meet the challenges of a low carbon environment is an area in which Bangor University is continuing to focus with the formation of the Welsh Institute for the Natural Resources. EU Convergence programme funded projects at Bangor such as BEACON, Welsh Institute for Sustainable Environment (WISE), and Sustainable Expansion of the Applied Coastal and Marine Sectors (SEACAMS) are all part of contribution to a low carbon environment. These three projectsare looking to support Welsh companies in the development of a range of products from bio-resources. These currently national networks are looking to expand to other European countries.

4 CURRENT AND FUTURE RESEARCH

In September 2013 a four year FP7 European funded project with the title “Eco-innovative, safe and energy efficient wall panels and materials for a healthier indoor environment” (ECO-SEE) started. This project aims to develop new eco-materials and components for the purpose of creating both healthier and more energy efficient buildings.It will address these issues through hygrothermal regulation as well as the removal of airborne contamination through both chemical capture and photocatalysis. The objective is to advance the state of the art in the technology and application of multifunctional bio-based insulation materials together with finishes and wood panelling to create internal and external walls.

BC will take the lead on one of the ECO-SEE work packages, “Beyond state of the art: eco-materials for passive indoor environment control.” This work will draw together many of the areas BC have been working in for many years: panel manufacture, resin chemistry, chemical modification, bio-insulation, formaldehyde chemistry and performance monitoring. There are considerable challenges posed by the project but without these ambitious targets the step changes required by society to make the adaptations to our environment will be even harder to obtain. The funding of this and other projects in this field starts to show hopefully that many issues once side-lined to the fringes are becoming mainstream concerns to the public, companies and policy makers.

5 CONCLUSION

Challenges for the natural fibre insulation manufacturing sector requiretechnical backing for production methods, contributing to reduction of manufacturing costs and increased market competitiveness. Specific areas includethe search for alternative bonding systems compatible with production protocols, leading to a lower environmental impact. In addition,additives such as fire retardants invite much room for improvement. Technical performance of the insulation products in combination with other products within elements and whole structures is another avenue, along with the development of behaviour change studies linked into marketing and dissemination activities. Researchingproduct durability and long term performance wouldallow a complementary understanding of the whole life benefits of these ‘new’ products.BC is looking to continue supporting relevantwork, and to further the understandingof dynamic thermal performance of materials through the addition of in-situ testing capability to the steady state thermal hot plate method.

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Bioclimatic Solutions Existing in Vernacular Architecture Rehabilitation Techniques

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ABSTRACT: The traditional architecture is founded as a defining element of the identity of a region, and its essence should be preserved and conserved by means of maintenance and recovery actions. Thus, the best solutions and proposals for intervention should be looked for but this doesn't imply a back to back innovation and at construction progress.
This work includes the description of techniques for maintenance and conservation of bioclimatic solutions found and inventoried in the north of the Iberian Peninsula, with special focus on a unique bioclimatic solution known as Sunspace, whose main advantage is to contribute significantly to the improvement of the thermal performance of buildings. It is also important to recover the historical heritage in a sustainable manner, allowing it to become an engine of development for both urban and small rural centres that exist in the periphery of the bigger cities.

1 INTRODUCTION

Popular wisdom related to the construction is a huge legacy in the history of vernacular architecture. The culture, history and traditions of the people of each region were continuously portrayed in buildings that are today part of our beautiful landscapes, constituting a heritage that needs to be preserved and appreciated.

The vernacular architecture has instinctively developed bioclimatic concepts that are nowadays scientifically valid. Given the lack of resources, the simplicity combined to the rationality has resulted in the application of techniques and solutions which, although rudimentary, maximize the use of materials and available energy. The adaptation to local environmental conditions implied that buildings have assumed an identity that characterizes the architectural image of each region.

The use of basic materials like wood, earth and stone has evolved to more complex solutions built with huge negative impacts on the environment. In recent decades, the sustainable construction concept has been developed based on the principles of recycling and maximizing resources, protecting and stimulating the creation of healthy environment which therefore lead to the reduction of the environmental impact of the construction sector. In order to support the agents in the construction sector, research projects and knowledge transmission on sustainable development construction have been carried on.

This work is part of the BIOURB project, a cross-border project between Portugal and Spain, which intended to contribute to the change of the current constructive model toward a more sustainable bioclimatic model, both environmentally and economically, reducing the energy consumption of buildings and raising the value of bioclimatic heritage along the border. In order to achieve the study a survey has previously been conducted on the bioclimatic solutions along the boundary, more specifically between the areas covered by the municipalities of

Bragança, Miranda do Douro, Vimioso, Mogadouro, Salamanca, Zamora and, in particular, areas of the natural parks of "*Los Arribes del Duero*" and "*El Sayago*".

2 IDENTIFICATION AND DESCRIPTION OF BIOCLIMATIC SOLUTIONS FOUND IN THE REGION

In the context of the assessment of regional bioclimatic solutions, the most prevalent were identified as:

i) The inertia wall, term usually used to describe the walls of high thermal mass, in which the most common material used for its construction was for many centuries the stone shale and granite and, to a lesser extent, the adobe. The construction system of the walls was greatly influenced by the local material available and the resources of the owners themselves. These walls of large thickness, in addition to transmitting stability and protection of buildings against water, acoustic insulation capabilities, also have greatly contributed to the temperature equilibrium within their areas;

ii) Gable roof, tile roofing, with the largest dimension oriented south and the smaller to north. The non-habitable attics have the particularity of effecting climate control in a passive way. In winter the stored products (crops, grass and agricultural tools) are used as heat accumulators, helping to warm up the living spaces and, in summer, so as to avoid overheating, there is natural ventilation through openings on opposite sides. The clay tile is the most widely used coating material having excellent characteristics, adapting well to the structure of light wood stand, with emphasis on resistance to temperature variations, low weight, durability, low water permeability and high mechanical strength. In colder regions, for the sake of ease in obtaining material, slate tiles are placed in the form of irregular pieces, arranged over each other;

iii) The green wall, a living system that provides a bioclimatic solution where vegetation plays the key role, contributing significantly to the preservation of biodiversity. In addition to creating enjoyable spaces that offer pleasant comfort sensations, through the effect of regulating the climate, temperature, humidity, wind moderation, it also refreshes and purifies the environment. The use of plant species on walls of buildings, often climbing deciduous or evergreen vegetation and ornamental plants that meet all or part of the facade, is a very old habit. Some of the traditional walls incorporate a support system (corbels) on the masonry, which serves as a guide for plant growth above the roofs, making the vegetation an integrated element of the building envelope;

iv) The transition oriented spaces such as balconies, porches and terraces were designed for people to enjoy the environment without leaving home, being often leisure spaces helpful to interaction between families and friends. Regardless of the main function, all these elements are spaces of integration with the environment and climatic attenuators, contributing greatly to the regularization of the temperature differences between the outside and inside. In addition, some of these solutions allow to differentiate the buildings assuming an identity by incorporating stone or wood elements with some ornamental details;

v) The geothermal climatization is based on the utilization of the thermal characteristics of the subsoil. Superficial layers of the subsurface retains a considerable amount of energy that the sun is responsible for renewing daily, and have the particularity to present temperatures that are constant throughout the year as well as heat increases with depth. This bioclimatic solution is reflected almost everywhere in buried building, defining spaces dug in the earth or rock, sometimes very rough with no natural light, that were the most often used for preserving food and wine. In *"Los Arribes del Duero"*, Spain, a region strongly influenced by the winery activity, one can observe spaces excavated in rock at a depth of 5-6 m (*bodegas*), which are still being used as touristic sites due to its typical characteristics;

vi) Green roof, is not as frequent as other bioclimatic solutions, but have been found in some 3000 years old constructions that are currently being used by shepherds and farmers as shelter and protection from the weather and for collection or storage of tools, agricultural implements and supplies. Such constructions are integrated in the space and merge with the landscape. Paraments have irregular masonry and the roof top is composed of slabs and piled rubble. The coverage has land and vegetation, consisting of local species such as moss and small herbs;

vii) The evaporative cooling process consists of the evaporation of water leading to a cooling of the environment. This strategy allows for air cooling before entering the building, and is related to Green Walls, Green Roofs, and with air/water exchange ducts. The outer traditional paving consisting of rock and soil also have the property to improve the microclimate regulating the hygrothermal stability in comparison with current airtight and waterproof solutions. In the Spanish region of *Fermoselle* and *Sayago*, there is a system of excavated cellars interconnected by a serie of ducts allowing the drainage of water that come both from ground infiltration and from wineries washing. These ducts serve simultaneously as a ventilation system. In summer, the air that enters from the outside through openings circulates through the ducts in which water circulates in the opposite direction causing cooling by mean of water evaporation, refreshing the upper spaces (usually housing);

viii) The Sunspace is a bioclimatic solution very characteristic of the traditional houses, mainly chosen in order to improve the comfort of the interior spaces, providing spaces for true pleasure.

Figure 1. Gable roof on capture coverage in *Rio de Onor*, Portugal

Figure 2. Green wall support system (corbels) on the masonry in *Fariza* de *Sayago,* Spain

Figure 3. A transition oriented space in *Cova de Lua*, Portugal

Figure 4. The geothermal climatization (Bodegas) in *Fermoselle,* Spain

3 BIOCLIMATIC SOLUTION – SUNSPACE

3.1 *First Approach*

Based on the above described solutions, characterization (types, ages, materials, building systems and their singularities) and survey of major anomalies have been carried on. For each bioclimatic solution, intervention proposals were drawn whether in favour of preservation and conservation than of rehabilitation and construction, ensuring and maximizing the potential of bioclimatic principles which govern the solutions. These principles of bioclimatic architecture aim to adapt the building to the local climate and the adoption of a set of practices and techniques based on the use of natural and local resources, minimizing both energy consumption and environmental impact. They also have the objective of optimizing the comfort and health conditions of users. The main conclusions of the work conducted on the Sunspace, which is one of the bioclimatic solutions more widely spread in the study area, are presented below.

3.2 *Identification and singularities of the constructive system*

The sunspace is a passive solar capturing solution, constituting an attached space in the building envelope, most often with direct connection to the living spaces. It's made of glass and has the main advantage of contributing to the greenhouse effect. In traditional houses, the sunspace and the interior spaces are generally separated by walls of high thermal mass, whose main characteristic is to absorb the solar radiation during the day, releasing it slowly to the interior during the night, reducing the daily temperature range inside buildings. In summer, in order to reduce heat gains, i.e. the amount of solar energy that focuses the glass surface, shading provided by the eaves of the roof or by deciduous trees is cleverly exploited. In addition to the thermal benefits, the Sunspaces are also decorative elements of the spans, contributing to the aesthetic composition of the facades, embellishing them and giving distinctive traces to each building. From the analysis of the different types of Sunspaces, from the simplest to the most elaborated, it can be concluded that these are harmoniously integrated into the design of the elevations, mirroring the image of the whole building and also the owner's economic capacity at the time of its construction. Furthermore, valuable information about the construction period can be obtained through the range of shapes, dimensions and proportions of the Sunspace. The majority of the Sunspaces present a wood and glass window frame, with or without exterior occlusion devices such as shutters or blinds. In the majority of the buildings, the sash windows incorporated in Sunspace are very characteristic of the Portuguese region while in the Spanish region, in addition to the use of wood, quite worked wrought iron was often used defining a very particular image of these buildings and featuring different epoch of construction. The ironwork is related to recent constructions from the late nineteenth century, in which they wore floral shapes and wavy, harmoniously worked, which expresses a clear aesthetics intention. The analysed Sunspaces are often located in an intermediate floor protruding out of the plane of the façade and, in many cases, they have their own roofing.

Figure 5. Ironwork Sunspace in *Ledesma*, Spain

Figure 6. Wood Sunspace in *Gáname*, Spain

3.3 *Identified Anomalies and Proposals for Conservation and Preservation*

The most frequent pathologies that occur in observed Sunspaces are entirely due to the employed materials associated to the lack of maintenance, the action of moisture and own aging and degradation of materials. It is worth to note that these elements are particularly sensitive because of their location in the building, subjected to a direct exposure to the sun which is more intense in areas oriented to the south and west, as well as to the action of rain and wind. In the case of Sunspaces composed of wooden structure, the atmospheric and biological agents are primarily responsible for the change in strength and the appearance of pathologies in the woods, including deterioration due to insect attack, the existence of warping and excessive clearances in the mobile joints, the reduction of active section and decay due to fungal attack (rottenness), and pronounced cracking due to insufficient or deteriorated surface treatment which do not effectively protects wood against ultraviolet rays. In the case of Sunspaces composed of wrought iron structure, primarily responsible for degradation are weathering and the action of moisture causing corrosion. In the case of metals, corrosion consists generally in the oxidation that causes delamination and reduction of cross section, thereby reducing the strength of the elements. Furthermore, gaps between metal frame and glass as well as loss of alignment (warping) have been detected due to lack of maintenance and/or excessive pressure exerted on the Sunspace (metal expansion due thermal or oxidation factors). We also found some examples painted with various coating shades. The paint is a coating material responsible for the protection of thermal fluctuations throughout the year. The painting system also provides a barrier effect which is to hinder the penetration of aggressive agents into the metal or the wood. Thus, in order to prevent rapid weakening of these structures, the factors responsible for the deterioration of the painting should be quickly corrected through maintenance work. Among the unconformities of the paint attention should be given to the deterioration of painting both in the inside and on the outside with peeling of the paint owing to moisture condensation which penetrates beneath the layer of paint, cracking and wrinkling due to the existence of several layers of paint and/or incompatible paint, spraying, presence of cracks due to the existence of moisture in the wood, infiltration, poor adhesion to the last coat of paint and eventually the accumulation of corrosion products in metal/paint interface.

Finally, there are anomalies common to both types of used materials, namely: the degradation of locks and ironmonger due to the usage and existence of moisture which leads to the oxidation of metallic elements, compromising the tightness and the consequent deterioration of wood; clearances between the ironmonger and the wood due to insufficient maintenance; fracture of glass or transparent plastic films as a result of the existence of actions of different sources such as accidental shocks, structural movements of the walls, ageing of the materials and sealing glass (putty or fillers) due to the continuous action of atmospheric agents. In both cases, the analysis of the preservation state of these elements must be carried out by a proper and careful visual and functional inspection. The maintenance works required for conservation and repair naturally depend on this analysis and on the degree of deterioration. Regarding wooden Sunspace, the "minor repairs" include small repair work on damaged areas, removal of deteriorated paint and surface preparation for application of new decorative painting, with characteristics appropriated to the timber protection. This work may also include the removal and replacement of windows and ironmongery as well as disinfestation by mean of applying toxic injection, spraying or brushing.

Concerning the wrought iron Sunspaces, the "minor repairs" include small repair work on damaged areas and local replacement, including substitution of sealing profiles, glass, sealants, screws and ironmongery in general. Cleaning, stripping, preparation and repainting with an anticorrosive paint scheme can also be considered. Wherever possible, the techniques and materials used in repair of any metallic element of this type of old buildings must be the same as those used in the original construction. This aspect can bring some restrictions in terms of techniques and materials to use. In more serious damage situations it can be necessary to perform a partial replacement of parts with a new material or a total replacement, keeping the original element design.

3.4 *The Traditional Architecture: an inspiration for the future*

Nowadays, with the limited resources of fossil energy and the environmental impact of buildings both due to excessive use of materials or to the resultant waste and pollution, it becomes imperative to heed the techniques and solutions that previous generations have adopted, identifying their strengths. The idea is not to copy ancient designs and solutions, but rather to take these principles for integration in current architecture.

Incorporating a Sunspace into a building as a bioclimatic solution has benefits both in rehabilitation and in new construction. The main guidelines for the implementation of Sunspaces are presented below:

- The Sunspace should be build-up on the facade facing south in order to maximize the capture of solar radiation (orientation with variation of up to 30° to the south orientation will have 90% of the maximum heat utilization);
- Glass surfaces oriented east and west should be minimized because they receive slight thermal energy by radiation in winter (resulting in negligible thermal gains), and cause overheating in summer whenever glass surfaces have not occlusion devices such as shutters or blinds. The north-oriented glass surfaces should be avoided since a more favourable improvement of the thermal performance of the building facades can be achieved by adopting isolation and without fenestration;
- Between the Sunspace and other usable spaces, a wall with high thermal mass should be placed in order to absorb the solar radiation that can be later transmitted to the interior. The wall colour influences its storage capacity as dark colours absorb more heat energy;
- The glass surface can be designed so as to have some inclination towards greater caption of solar gains; however, this solution requires additional cares like the strength against atmospheric agents (snowfall, hail), the greater complexity in placement and operation of shading devices, and the difficulty of cleaning access;
- In cold climates such as the one in current study it is advisable to use double glazing in order to reduce heat loss as well as to contributing to sound insulation. To preserve existing window frames one should take into consideration the thickness of the frame which may constrain the use of double glazing. Rubber seals and coating, mastics and masses can be employed in order to improve performance and durability at critical points;
- The dimensions of the glass must be made compatible with its thickness, as it is a brittle material;
- Exterior occlusion devices (such as shutters) must be placed so as to minimize heat losses during the night and to prevent overheating during the summer;
- Possible shading due to neighbouring buildings or other elements must be taken into account;
- Adjustable or mobile thermal insulation of the area surrounding the Sunspace must be considered so that the different needs of heating and cooling both in winter and summer can be optimized;
- Controlled ventilation should be provided in order to avoid condensation. In case of heat transmission by convection, the openings have to be strategically placed. Warm air enters the building through openings placed at the upper parts of the walls while interior cold air is expelled to the Sunspace through openings placed at the bottom of the walls;
- Ecological footprint of employed materials should be taken into account. For instance, wood has the advantage of being a natural element available in the region, also advisable because of its low thermal conductivity (low ability to conduct heat). A wall made of stone, which is an abundant resource in the region, is a good solution due to its large mass and hence thermal inertia;
- The system idealization should take into account the dismantling and end-of-life regarding subsequent reuse of materials.

4 CONCLUSIONS

Current work, which is part of the BIOURB project study, has as its main objectives the processing of information on the biodiversity of the region as well as establishing constructive proposals intended for conservation and rehabilitation. The purpose is to assist the various stakeholders in the construction process in the decision-making related to intervention in the built environment, aiming to enhance both cultural heritage and environmental sustainability. This sort of work should be helpful in order to respond to European and international commitments regarding climate changes, and reduction of the consumption of fossil energy.

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Overview of Industrialized Technological Solutions for Temporary Facilities in Construction Sites

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ABSTRACT: According to the current Regulatory Standardin Brazil, construction siteis "a fixed and temporary workspace where the support and executionoperations of a construction project take place". Temporary facilities can be defined as thosewhich support the activities of the construction project and are expected to be removed when the project is finished. As a working environment, the temporary facility must provide quality, safety and health conditions to workers, as well as include sustainability aspects in its conception and production, allowing for reuse after disassembly. This shows the importance of knowing the different technological solutions for temporary facilities. This article aims at providing a brief introduction to the identified alternatives and classifying them. Theresults show that there are different systems, with technical characteristics and recommendations which must be known in order to guide the development of projects, as well as to provide the sustainability to the product and comfort to the workers.

1 INTRODUCTION

While projecting the worksite, planning the work conditions is as important as planning the physical flow of materials needed to carry out the work. Therefore, Trotta et al. (2012) state that in order to have an organized project it is essential that the common areas in the workplace are properly planned and of adequate size, allowing workers to perform their tasks properly.

The fact that workers usually spend around nine hours a day at the construction site highlights the importance of projecting environments which provide comfort and satisfaction. Besides, according to Cesar et al. (2011), a good aspect in the workplace improves the moraleof the workers and reduces the risk of accidents. Furthermore, the authors of this article argue that construction companies should value not only the quality of the services provided, but also the quality of life of their workers during the execution the construction project.

In this context, due to the obligatory implementation of living areas in line with regulatory standards NBR 12.284:1991 (Living Areas in Construction Sites) and NR-18 (Work Conditions and Environment in the Construction Industry) (Brazil, 2012), temporary constructions are among the most intensely monitored by the Labour Ministry, once they provide humane working conditions (Trotta et al. 2012). Among the environments described in the regulatory standards are the sanitary facilities, kitchens, dressing rooms, cafeterias, outpatient clinics, dormitories, laundries, and leisure areas.

It is understood that the construction site layout is not a single, fixed project because while thework is being developed, the site takes different configurations according to each phase of the project. Likewise, Trotta et al. (2012) acknowledge that the living and administration areas will also change as part of a production cycle whichconsists of construction, expansion, and demolition. Therefore, depending on the construction system chosen, there is great generation of rubble and waste materials not reused in future projects, leading to new implementation costs.

In this sense, Saurin&Formoso (2006) advocate the standardization of temporaryfacilitiesas a strategy for companies building with similar types of projects, where temporary facilities would have identical characteristics in every worksite, as long as the peculiarities of each layout are respected. The authors believe this standardization is environmentally justified and recommended due to the repetition of the cycles of facilities, regardless of the technologyemployed.

According to Arslan (2007), building temporary facilities quickly and with low production cost is only a matter of habit since these facilities can be built with sustainable materials and components that can be assembled and disassembled, are recyclable, and even reusable. This is currently shown in construction systems developed specifically for the use in temporary settings.They can be stored and reused countless times, according to the needs of each project (Santo Jr. &Azzolini 2009).

Therefore,it is noted the use of different construction technologies fortemporary facilities with good quality for use and operation, possibility of reuse and adopting appropriate sizing criteria according to current regulations. In order to make the decision regarding the most suitable type of temporary facilities,one should raise the questions which are important and indispensable to the user’s needs.

Advanced methods can be used in solving this type of decision making, as they seek to clarify the decision-maker the possibilities of choices. These methods support the decision making process, but must be grounded on existing information, incorporating values of the agents, in search of the best solution.

Thus, this article proposes a brief reflection and organization of the typology of technological solutions currently used at construction sites in the Brazilian market, focusing on the characterization of the main features of each system. Based on this first phase of the research guidelines for the preparation of multi-criteria analysis in future researches will be proposed.

2 SUSTAINABILITY OF TEMPORARY CONSTRUCTIONS

Being aware of the need to encourage the improvement of workplaces, the environmental certification systemprocedures started taking into account issues of sustainability in construction sites as assessment and scoring criteria. However, studies relating the subject to workplaces and facilities in construction sites are scarce. In general, environmental certification systems consider the need to create low-impact construction sites but the need for temporary constructions is not always clear.

In his study for building living facilities, Arslan (2007) states that during the conception process, the following principles should be followed:

- Lowering the energy demand and the consumption of operating materials;
- Utilization of re-useable or recyclable building products and materials;
- Extension of the lifetime of products and buildings;
- Risk-free return of materials to the natural cycle;
- Comprehensive protection of natural areas and use of all possibilities for space-saving construction.

However, Degani (2012) argues that the project of temporary facilities should consider:

- Areas planned for the management of administrative residues;
- Areas planned for the management of inputs;
- Ergonomically appropriate areas planned for the flow and permanence of people (health and productivity);
- The promotion of well-being;
- Cleanliness;
- Meeting the needs of thermal and acoustic comfort,according to the climate and wind conditions at the site;
- Communication to raise awareness of responsibilities and guidance;
- Disassembly and recyclability of facilities.

A number of performance requirements must also be met before choosing and projecting the facilities. Rodrigo et. al (2012) describe the main performance requirements that temporary facilities of construction sites should meet based on the Brazilian performance regulation and the Aqua method (adapted from HQE® French method).

Reis, Souza & Oliveira (2004) highlight that the word temporary should not imply precarious planning, especially because these facilities are crucial for the activities in a construction site., Nevertheless, civil construction companies don't always assess the quality and maintainability of temporary facilities, which tend to be built carelessly, without previous project, and by unskilled workers.

One of the contributors to this carelessness is their short-lived nature, once temporary constructions don't last as long as the building itself. Part of the living areas need to be moved to areas which have already been built so that the outer areas of the project can be finished. Therefore, company owners are not willing to invest in these transitory facilities, which are usually improvised with low-quality materials or poor physical integrity (Oliveira &Leão, s/d).

The planning and execution of the construction site layout is not time consuming and requires low investments when compared to the overall project. So, not managing this stage effectively is not justifiable, since the resources allocated are not significant when compared to the benefits provided (Saurin & Formoso 2006). Besides, before adopting sustainable technologies for temporary constructions, Reis et al. (2004) recommend a detailed analysis of the real benefits provided by each system, keeping in mind their environmental, economic and social impacts.

3 RESEARCH METHOD

This paper is an exploratory study still underdevelopment. Our method consisted of documental analysis, bibliographical reviews, searches in commercial websites and trade fairs which focused on innovations in civil construction in order to identify the current technological solutions developed for industrialized temporary facilities. Then, solutions were grouped according to the characteristics of each system.

4 TECHNOLOGY OF TEMPORARY FACILITIES

According to Birbojm & Souza (2001), construction companies often make choices without considering the advantages and disadvantages of the alternatives available, which results in more expensive, poorly projected and uncomfortable living areas. Nowadays there is still little investment in rationalized solutions,such as prefabricated alternatives easier to assemble and resulting in less waste or systems manufactured with long-lasting and reusable materials.

Although plywood systems prevail in most construction sites, there are several different options for temporary facilities. Each option has a specific cost-benefit profile (Saurin & Formoso 2006). Therefore, different technological solutions for industrialized temporary facilities will be presented here in order to provide examples and compare the characteristics of the main alternatives available in Brazil.

4.1 *Prefabricated Wooden Structures*

Prefabricated wooden structures (Figs. 1-2) are based in the industrialization of its components, that is, several modular, self-supported panels, delivered at the site. The components are treated against microorganisms and assembled according to the projects provided by suppliers, lasting longer than the traditional plywood system and being reused 5-7 times (Birbojm & Souza 2001).

Different kinds of wood are possible, including Oriented Strand Boards (OSB). OSBs are plates of oriented wood bound with phenol, a highly weather tight resin. The resistance of OSB is similar to that of plywood, and it may be used together with conventional methods or as industrialized components alone. Its high resistance against delamination and warping ensure proper hygiene, durability and appearance, all required for the quality of a building.

There are combined “Cement Wall” technologies made with panels raised with reforestation wood laths covered internally and externally with OSB and cement plates, providing increased resistance to moisture, fire, and impact. They also provide better thermal and acoustic conditions (Novo Espaço 2013).

Figure 1. OSB prefabricated temporary facilities.Source: http://www.lpbrasil.com.br/aplicacoes/

Figure 2. Prefabricated temporary facilities made with pinewood panels.
Source: http://www.canteiro.com.br/

The installation at the site requires shallow foundation according to the requirements of each soil or building type.

4.2 *Cellular Concrete*

This system uses cellular concrete modules interconnected by a metal framework (Figure3)and its advantages are the excellent thermal and acoustic characteristics, fast execution and compatibility with any project size. Cellular concrete is also treated with inert, inorganic elements which prevent against pests and fire, ensuring they are weathertight and have good finishing (Fig. 4).

Figure 3. Assembly of temporary facilities in cellular concrete
Source: http://www.novoespaco.com.br

Figure 4. View of temporary constructions in cellular concrete
Source: http://www.prefacc.com.br/

Similar to prefabricated wooden facilities, it also requires shallow foundation based on the characteristics ofeach soil or building type.

4.3 *Metal Containers*

Metal containers are commonly used for being light, easy to transport, reusable, and weathertight, besides the fact that they do not rely on foundations, and don't take long to assemble or disassemble. Metal containers are versatile, allow for different internal setups and may even be used as bathrooms (Fig. 5).

Birbojm& Souza (2001) consider the high renting costs and their considerable thermal and acoustic discomfort the key disadvantages of metal containers, so climate control units or air conditioners are required(Fig. 6).

Containers with thermal and acoustic solutions are also available today. These containers use panels which muffle the noise and provide better thermal conditions, improving the quality of life at the construction site. These panels are composed of two 1.9 mm thick galvanized steel plates with an expanded polystyrene (EPS) plate in between them (Eurobras 2013).

Saurin&Formoso (2006), however, state that although there are containers with thermal insulation available for purchase, they are often not used because of their high cost. To minimize these impacts the authors suggest simple measures such as white as the outside color, a roof on top of the container, and at least two openings for adequate, natural ventilation.

Figure 5. Internal detail of a container used as a bathroom.
Source: http://www.containeraracaju.com.br

Figure 6. External view of metal container with air conditioning.
Source: http://www.karmod.eu

As previously mentioned, one of the advantages of containers is that several modules may be disassembled and transported together, or they may be transported on top of each other (Fig.7). There is one feasible innovation – the transportation and storage of empty containers developed by CargoShell (Fig.8). The fact that containers need less space to transport cuts costs and adds aspects of sustainability, such as reduction of carbon emissions.

Figure 7. Containers transported either assembled or disassembled.
Source: http://www.eurobras.com.br/

Figure 8. Disassembling load container for transportation. Source: http://www.cargoshell.com/concept_en.php

4.4 *Galvanized Steel Plates*

Temporary facilities made of galvanized steel plates (Figs. 9-10) are mechanically resistant and show other advantages related to assembly and disassembly: they do not require foundation and are highly weathertight, allowing for multiple reuses. However, similarly to metal containers, thermal conditions are not good so,isothermal panels on the roof are an option.

Figure 9. Temporary facilities in galvanized steel.
Source: http://cmcmodulos.com.br

Figure 10. Two-stores temporary facility in galvanized steel.
Source: http://cmcmodulos.com.br

4.5 *Sandwich Wall Panel with insulating core*

There are also temporary constructions formed by sandwich panelsconsisting of two sheets anda core insulationwhich increases the thermal comfort. The exterior sandwich panels may be painted galvanized steel sheetsor panels reinforced with fiberglass or cement. There are several solutions for insulating the core. The product with higher utilization in the core is made of foam polystyrene (EPS) which can be used for panels for roofing and walls (Fig. 11). Currently some companies are using polyurethane (PUR) and polyisocyanurate (PIR), which are more structured components with more insulating ability of the EPS (Fig. 12). Another solution can be filling the core with lightweight concrete (polystyrene concrete). In addition to the light weight, this system also has high mechanical strength, durability, reduced energy consumption and fire resistance.

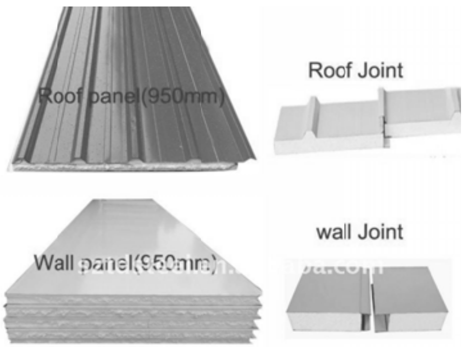

Figure 11. Sandwich panels with insulating cores and execution details. Source: http://www.china-goodhouse.com/news/show/170

Figure 12. Building with sandwich panels thermo acoustic. source: http://www.danicacorporation.com/ sfDanica2/web/index.php/

4.6 *Structured Sheds*

Structured sheds in laminated tubes of polyvinylchloride(PVC)withPVC canvas (Fig. 13) are appropriate as storage rooms and as shelter for workers at construction sites. Its galvanized steel framework does not require internal pillars, allowing for free internal areas (Fig. 14). Structured sheds do not require foundations; they are built on plain concrete floor. Among the benefits of canvas, it is worth noting the resistance to ultraviolet and weather protection, ensuring durability and vivid colors for a longer time; antifungal action and the fact that does not propagate fire since eliminated the source.

Although transportation, assembly and disassembly are easy and free of noise or debris, sheds tend to be wider and higher (at least 4m) and overall bigger than the conventional temporary facilities. This might be one of the reasons they are not used in all kinds of construction sites, especially when vacant areas are small.

Figure 13. Example of structured shed
Source: http://www.sansuy.com

Figure 14. Shed, without internal pillars
Source: http://www.sansuy.com

4.7 *Canvas Barracks and Tents*

Barracks and tents are light modular systems that provide resistant shelter. They are easy to assemble and transport, and resist great weather changes. Canvas barracks and tents (Fig.15) are reusable, waste-free temporary facilities. A steel framework provides a rigid shape, and does not require specific foundations; they are stable in any soil and, as in structured sheds, do not have internal columns (Fig.16).

Figure 15. Example of canvas barrack
Source: http://vrb848.com.br

Figure 16. Obstacle-free interiors
Source: http://www.revistatechne.com.br/

5 CONCLUSION

Every construction project, regardless of size, requires temporary facilities as support areas. For a construction site to be considered sustainable the conditions of the activities performed must be verified and the number of workers quantified. Only then can living areas be appropriately sized according to current regulations, and proper investments can be made in high performance, high quality technologies that can be reused several times.

Our research has shown that the supply chain of temporary facilities is aware of the importance of developing products which are environmentally sustainable and meet the needs of the people who will be working at the sites. The information about each technology solution should be available as well as the decision parameters, which should be arranged for a multi-criteria analysis.

The requirements for temporary facilities forRodrigo et. al (2012) can be listed in 15 categories: structural performance, fire safety, safety in the use and operation, tightness, thermal performance, noise performance, luminous performance,affordability,tactile and visual comfort, environmental suitability (waste, energy, water consumption and choice of materials).

Thus, the constructioncompanies must still analyze the options and calculate the costs of acquisition, implementation, and maintenance, as well as its durability and length of use, together with the likelihood of reuse. It is also important to consider whether or not they are easy to assemble, transport, and disassemble; thermoacoustics and visual impact must also be assessed, among other crucial criteria that should always be taken into account according to the needs of each particular project.

Then, it is important that the supplying companies also provide information on whether or not they meet the requirements regarding sustainable construction sites certification, highlighting the advantages of each solution in terms of economic, social, and environmental aspects.

The work environment should be designed considering the parameter of social sustainability for the site to have decent working conditions for workers.Some environmental certification systems consider this a very important aspect for the score of the enterprise.

Finally, the proper study of temporary facilities at the project site will result in better quality of life in the workplace, less waste during disassembly, and reduction of costs of acquisition during the service life of the facilities. One of the main expectations should be the increase in motivation and productivity due to safer and more dignifying work conditions.

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Chapter 9

Urban Regeneration

Science of complexity for sustainable and resilient urban transformation

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ABSTRACT: Sustainable buildings are integrated in urban complex systems through a variety of scales from the cluster of buildings, to the neighborhood urban fabric, to the district scale, to the city scale, and up to the metropolitan scale. All these upper scales impact on the energy efficiency and the resilience of sustainable buildings that cannot be assessed without taking into account the spatial scales and the material flows of the complex urban system in which they are integrated.
Like all living organisms, the different scales of cities are open systems and sub-systems constantly exchanging energy and matter with their environment in order to maintain their existence and create new structures. Flows run through them ceaselessly: people and goods, all forms of energy, water, wind, sun, and natural forces. Open systems cannot be described using classical thermodynamics of equilibrium, as developed in the 19th century by Boltzmann. To understand them, we have to turn to the more recent work of Ilya Prigogine on the theory of dissipative structures, far-from-equilibrium thermodynamics, and self-organizing systems.
The theory of dissipative structures focuses on self-organizing phenomena, on the seemingly spontaneous emergence of an order, that is to say of a spatial and temporal morphology within a system made up of a great number of entities. In all cases, dissipative structures involve a "symmetry break". A homogenous, undifferentiated state (spatially and temporally) gives way to a heterogeneous, differentiated state that is less symmetrical than the prior one.
The urban structures resulting from the maximization of exergy predicted by Prigogine are fractals. They obey scaling laws, that is to say their elements and connections are distributed according to Pareto distributions, that is inverse power laws. These laws are present in cities that have evolved across long periods of time. They explain their efficiency and their resilience. They should be applied to transform our present cities in order to increase their efficiency and resilience. These underlying laws are strong tools for transformative policies to achieve energy efficiency and resilience targets as well as a scientific basis for spatial planning assessment systems.

1 INTRODUCTION: SPATIAL PLANNING AND PARETO DISTRIBUTIONS

1.1 *A complex systems approach*

Spatial planning both for the geometry of the urban form, for the topology of the relations between the urban elements and for the distribution and synergy of flows is the most powerful policy to achieve EU 20-20-20 targets both on an energy, a social and an economic base. Modernist urban thinking seeks to simplify building and urban system by breaking them down into subsystems whose individual optimization leads in reality to the sub-optimization of the whole. Indeed, seeking efficiency for each sub-system separately is incompatible with a complex systems approach that alone enables a global optimization. The sub-systems of historical cities are entangled and interwoven in a deeply structured and complex manner. This allows them, even when they are individually sub-optimized, to globally optimize the efficiency of the city.

Urban morphology, the spatial distribution of activities, the mix of usages and energy production and demand at the urban block scale, its adaptive potential for different uses, the structure of urban networks, the street patterns and their potential of transformation over time toward a fine grain and a human scale, are crucial aspects of a holistic assessment of sustainable buildings. Sector-based and mono-scale approaches are not sufficient. An innovative and comprehensive framework is necessary to encompass the complexity of sustainable buildings integrated in urban complex systems evolving over time. This holistic approach should integrate all the sectors that matter for building and urban sustainability, as well as all the spatial scales, from the sustainable building scale up to the neighborhood and city scale.

1.2 *Cities are dissipative structures*

Cities are complex systems that evolve far away from the equilibrium. In thermodynamic terms they are dissipative structures that become more and more complex in order to dissipate the flows of energy in an efficient way. In a very subtle way characteristic of dissipative structures “at the edge of chaos”, the complexity of the urban elements interrelationships creates constantly changing overall patterns that never stabilize in a finite form. This constant transformation of urban dissipative systems is cities morphogenesis.

By studying urban morphogenesis through the prism of thermodynamics for open systems, we can perceive their fractal structure – that is to say, the scale free structure according to multiple Pareto distributions that underpins their efficiency.

A highly structured scale free system will utilize energy more efficiently than a more disordered system. Bejan’s constructal law posits that for a flow-driven system to live and grow it must develop in a way that provides easy access to the flows running through it. Reis has demonstrated the equivalence between the constructal law and the minimum entropy output predicted by Prigogine: the structures resulting from constructal theory are those that achieve the objective of maximizing exergy. The optimal structure: an arborescence, with a main flow (the trunk) divided into secondary channels (the branches), which are subdivided into capillaries (twigs and leaves). Trees are fractal structures: they display the same pattern on every scale of branches dividing into smaller channels.

1.3 *Pareto distribution and scale free structures*

The self-similarity of the parts and the whole can be summarized in a classical distribution in economy, the Pareto distribution, or inverse power law. The Pareto distribution relates the large, the intermediary and the small in measurable ways. It states that in a complex well-balanced system the frequency of an element of size x is proportional to the inverse of its size at an exponent m[1] characteristic of the system. In other terms there are few big elements, a medium number of medium-scale elements and a very large number (a “long tail”) of small-scale elements, and the relative frequency of each type is determined by the mathematics of the Pareto distribution.

One of the main points for understanding the connection between the physical and topological structure of historical cities and their capacities of efficiency and resilience is the equivalence between fractal structure and the Pareto distribution[2]. By definition, a fractal structure has the property of scale invariance, which means that the distribution is the same on all scales. Mathematically this is written as $p(bx) = g(b)\ p(x)$. This functional equation is verified by any p fractal distribution. Its resolution is done simply by analytical methods, and leads to a unique category of solutions: $p(x) = kx\text{-}a$, which is the exact definition of the Pareto distribution. This means that there is a mathematical equivalence between the Pareto distribution and the fractal distribution.

[1]In spatial planning or in network design (street patterns, subways) this exponent can be interpreted under certain conditions as a fractal dimension, characteristic of the self- similarity properties of the system (it is generally around 1.2 for networks, between 1.6 and 1.85 for built footprints depending on the compactness of the city).

[2]Newman MEJ. “Power laws, Pareto distributions and Zipf's law,” in Contemporary Physics, 46:5, 2000, pp. 323-331.

This long tail of Pareto distribution is at the origin of the most impressive business success stories of the Internet economy, such as Amazon. Instead of relying only on a few blockbusters (large elements sold by millions), Amazon has cut all the logistic costs of traditional distribution channels and made available to the world audience a long tail of millions of highly-differentiated products that even if sold at a few dozen samples each represent altogether a volume of sales much more higher than the blockbusters. It is full of lessons to see that highly successful agglomeration economies follow in their spatial organization the same patterns that the most successful businesses. The underlying reason is that economic efficiency and spatial efficiency are two different aspects of the same coin: distribution efficiency in a highly differentiated world where exergy is maximized.

Paris network of public parks is spatially distributed through a Pareto law.

1.3.1 *Green spaces distribution in Paris*

The spatial distribution of green spaces in Paris results from policies and regulatory urban planning that have ensured that every citizen lives less than 400 meters from a public park, square or garden. This target has been reached whereas green spaces (without the woods) only represent 5% of the urban area. There are a few large parks that allow a wide range of activities for residents, and a very big number of very successful pocket parks for daily families activities and intergenerational mix (260 green spaces less than ½ ha). This long tail distribution of parks follows again a Pareto distribution (Schattner, Bourdic, and Salat 2012), which is an important tool for optimization in economy and urban planning. As a comparison, green spaces in Beijing represent 30% of the urban area. Most of the green spaces are very big parks, and the long tail of small parks lacks. As a result, residents live more than 3 km from public parks in average.

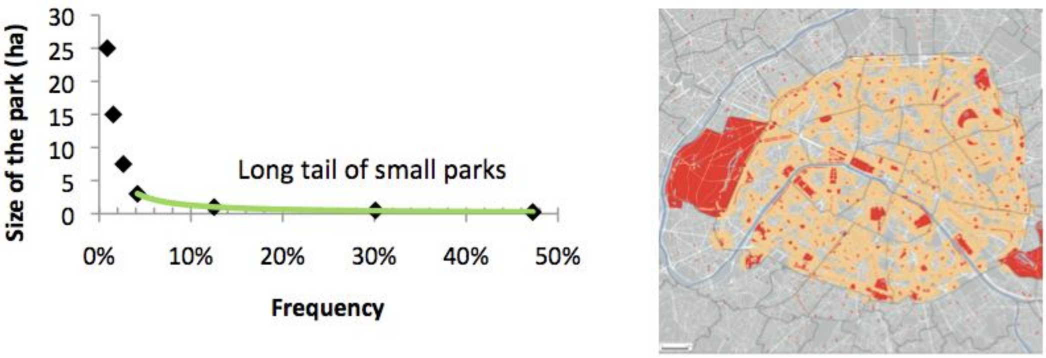

Figure 1. Long tail distribution of parks in Paris, in green (Left), ensures 5 min. walk accessibility to parks (red) to 80% of people (orange) (Schattner, Bourdic, and Salat 2012).

The metrics of street patterns in Paris follows a Pareto distribution as regards the linear density of different street types.

1.3.2 *Street patterns in Paris*

The street network in Paris is distributed according to a Pareto distribution: 60% of the streets (the historical street network) are less than 12 m wide and accommodate low speed traffic. Avenues and boulevards 20 and 30m wide accommodate faster transit and public transportation (bus and tramway).[3]

[3] Bourdic, L. and Salat, S., Street patterns in Paris, Urban Morphology Institute Working Paper, 2012.

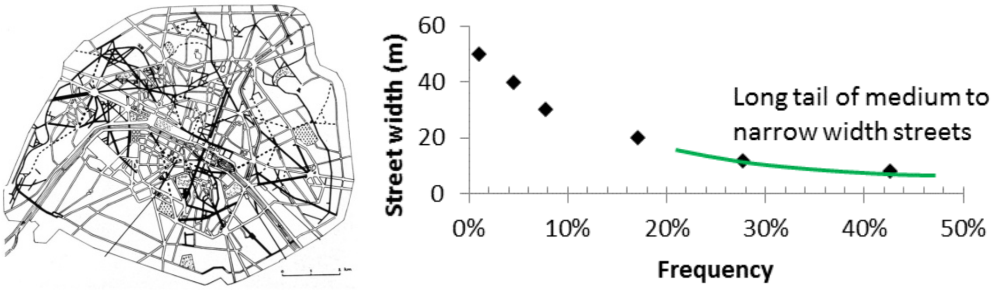

Figure 2. Left: Paris street network. Right: Long tail of medium to narrow width streets ensuring high accessibility and walkability.

2 CREATING FORMS BY BREAKING SYMMETRY

Historical cities, over the course of their long history, were slowly transformed by incremental phenomena of destruction and reconstruction of the urban fabric. Structures that were not resilient enough were eliminated. And so historical cities have come down to us with extraordinary capacities of efficiency and resilience. In a process of ongoing, spontaneous self-organization to adapt their forms to fluctuations in their environment, historical cities acquired the capacity to absorb fluctuations by reinforcing their structure and order, and becoming more complex.

2.1 *Open systems far from equilibrium*

Thermodynamics, a complexity science par excellence, enables us to describe vast systems, sites of numerous microscopic events, flows of energy and matter, by synthesizing them on a global scale by macroscopic parameters. This is exactly what cities are and how they can be described: indescribable in their tiny details, but globally structured by the interactions between their forms and the flows that run through them.

Cities are not closed systems anyway and thus they do not obey the second principle of thermodynamics,[4] and this from the very start, approximately five thousand years ago, when the surpluses produced by improved farming techniques put cities into a creative disequilibrium with their environment.

2.2 *Symmetry breaks and the emergence of complexity*

As Ilya Prigogine and Isabelle Stengers point out, “Equilibrium structures can be seen as the results of statistical compensation for the activity of microscopic elements (molecules, atoms). By definition they are inert at the global level. For this reason they are also ‘immortal’. Once they have been formed, they may be isolated and maintained indefinitely without further interaction with their environment. When we examine a biological cell or a city, however, the situation is quite different: not only are these systems open, but also they exist only because they are open. They feed on the flux of matter and energy coming to them from the outside world. We can isolate a crystal, but cities and cells die when cut off from their environment. They form an integral part of the world from which they draw sustenance, and they cannot be separated from the fluxes that they incessantly transform.”[5]

This is a crucial distinction: while classic thermodynamics predicts the dissolution of any ordered structure and the ultimate reduction of any complexity, Prigogine's theory develops the creative potential of non-linear, far-from-equilibrium thermodynamics. “Prigogine shows that the

[4] If cities obeyed the second principle of thermodynamics, like all closed systems, their entropy would grow in a continuous, irreversible manner. In other words, the system would tend to become uniform and singularities to dissolve. The state of maximal entropy, the state toward which all closed systems tend, is the most disorderly state, that is, the most undifferentiated possible state. The structure that results is called a structure in equilibrium.

[5] Ilya Prigogine, Isabelle Stengers,*La nouvelle alliance*, Paris, Gallimard, 1979, p. 198.

second principle does indeed exclude the emergence of an order when the systems evolve closeto thermodynamic equilibrium, but this is no longer the case far from equilibrium. More precisely, the passage from disorder to order is compatible with this principle when the systems studied satisfy two very specific conditions. First the systems have to be open, which means that there has to be an exchange of matter and/or energy with the outside world. This condition releases from the law of increasing entropy and hence from the disorder imposed by the second principle of isolated systems."[6]

The theory of dissipative structures focuses on self-organizing phenomena, on the seemingly spontaneous emergence of an order, that is to say of a spatial and temporal morphology within a system made up of a great number of entities. In all cases, dissipative structures involve a "symmetry break". A homogenous, undifferentiated state (spatially and temporally) gives way to a heterogeneous, differentiated state that is less symmetrical than the prior one.[7]

Like in physics and like in semiotics, breaks of symmetry in cities create structure and meaning. Passeig de Gracia in Barcelona connects the original city that became the Barrio Gotico to the preexisting village of Gracia and is thus slightly shifted in the orthogonal grid of the city's extension without being a diagonal that would be integrated in the grid. It has been developed first in an astounding Art Nouveau Style. These 2 breaks of symmetry in space and in time have given Passeig de Gracia a central connective position and created a subtle large-scale order in the repetitive urban fabric of square blocks of Cerda's Eixample. The crossing of the 2 diagonals that Cerda intended to become the new center of the city did not break any symmetry and remained marginal compared to Passseig de Gracia.

2.3 *Breaks of symmetry, information theory and centrality in cities*

Information theory can provide a metrics of cities breaks of symmetry in diversity of uses and thus in complexity. Shannon and Weaver proposed an equation similar to the entropy equation to measure the quantity of information a message contains. A bit of information is defined as the amount of uncertainty that exists when one has to choose between two possibilities: for each possible trajectory an information bit is added.

If we consider that each legal entity of the urban system (economic activities, associations and institutions) is represented by an ideogram (the Urban Ecology Agency of Barcelona has created a urban dictionary with more than 2.000 ideograms that correspond to the European classification of economic activities), a word in the urban dictionary, as the Chinese and Japanese dictionaries do, we can build urban messages and calculate the amount of information they contain.

The value obtained (H) is the measure of diversity – that is urban complexity – and is, in some way, the measure of organized information. Legal entities are carriers of information and also of the ability to control the present and influence the future. We can measure the organizational level of a territory, as well as its capability to exchange information, partly through these analyses of information diversity. Knowing the number of different carriers of information in a specific space allows us to be aware of the breaks of symmetry in the information distribution and thus in the organizational level across the urban territory. If the analysis is carried out at different moments, it allows to measure if the information diversity increases or decreases and in which parts of the city it does so. Diversity indexes have a greater meaning when applied to the temporal evolution of the urban territory. Studying the increases or decreases of H in a specific territory allows us to

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[6]Alain Boutot,*L'Invention des formes. Chaos, catastrophes, fractales, attracteursétrangeset structures dissipatives*, Editions Odile Jacob, 1993, p. 90-91.

[7] Alain Boutot points out that Erwin Schrödinger (1887-1961) already expressed this idea. Schrödinger was trying to understand how living organisms, which are the very paragon of organized beings, maintain their organization despite Carnot's principle. "To explain this phenomenon, he formulated the following hypothesis: living organisms are open systems that avoid the thermal death predicted by the second law by constantly feeding on negative entropy.""A living organism, according to Schrödinger, constantly increases its entropy – or one could say, creates positive entropy – and thus tends toward the dangerous state of maximal entropy, which is death. It can only hold it at bay, that is, stay alive, by continually extracting negative entropy from its environment." (E. Schrödinger, *Qu'estceque la vie ?* Paris, Bourgois, 1986, p. 172).

approach some of the potential dysfunctions of the urban system, as well as the elements that provide stability.

When we evaluate the relation between the consumption of resources (E) that are necessary to keep a specific organization (H) through time, we obtain an equation of efficiency (E/H) that may become a guiding function for urban policies.

Mapping urban Shannon information on a territory reveals the breaks of symmetry in the development of the urban fabric, and in some cases its elements of centrality.

Coming back to Barcelona, we can see how the breaks of symmetry in information structure the apparently spatially uniform Cerda plan. 34% of Barcelona has values over 6 bits of information per individual, the Eixample and the Barrio Gotico being the urban territory with a greater diversity. 87% of the Eixample obtains values over 6 bits of information per individual, becoming the fabric with a greater diversity of legal entities (economic activities, associations and institutions) in a diameter of hundreds of kilometres, making up the greatest area of centrality in Spain, whose influence goes beyond the borders of Spain (Busquets, Corominas, 2010). The Eixample has been built and is still being built slowly, as complex systems are built in nature. Compared with natural systems, it could be equated to the tropical rainforests or the coral reefs. Both are systems with the highest diversity on Earth.

Part of this diversity originates from the subversion of the original Cerda plan, which has been modified by closing the blocks and filling partially their interiors. This densification has first allowed a concentration of industrial production, and today an adaptive diversification of activities, making it possible for the types of activities to change over time. The Eixample radiates activity around it; it is a true heart that beats diversity, extending the urban complexity by the pedestrian axes that pass through it. The part of the Eixample around Passeig de Gracia and the part of the Barrio Gotico connected to it by Passeig de Gracia show the highest level of diversity and organizational structure in terms of information theory. They are the true heart of the city.

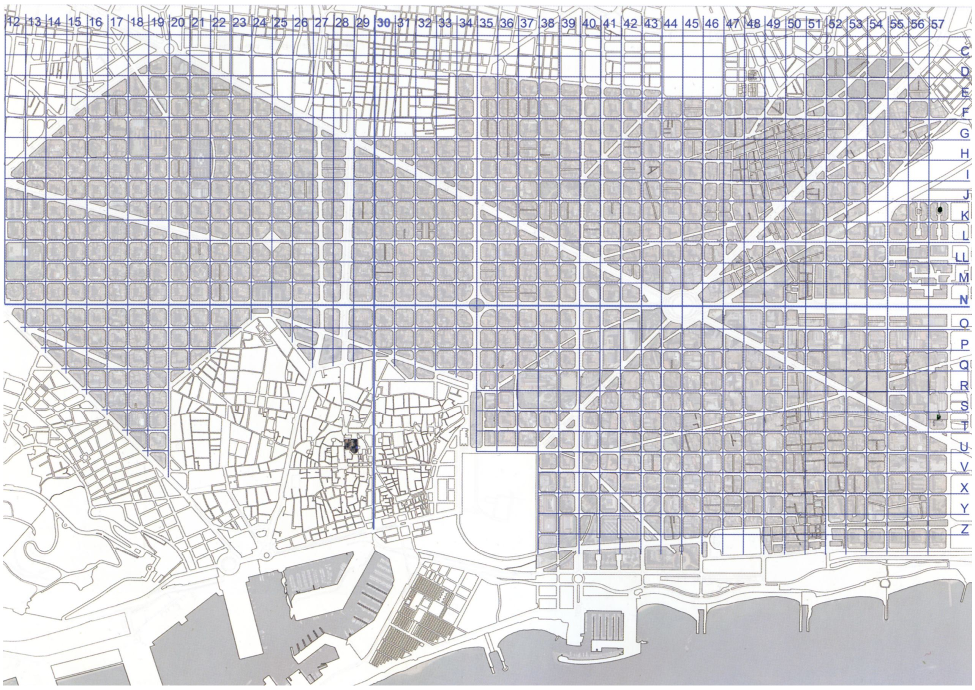

Figure3. Barcelona grid of square blocks in the Eixample with the Barrio Gotico.

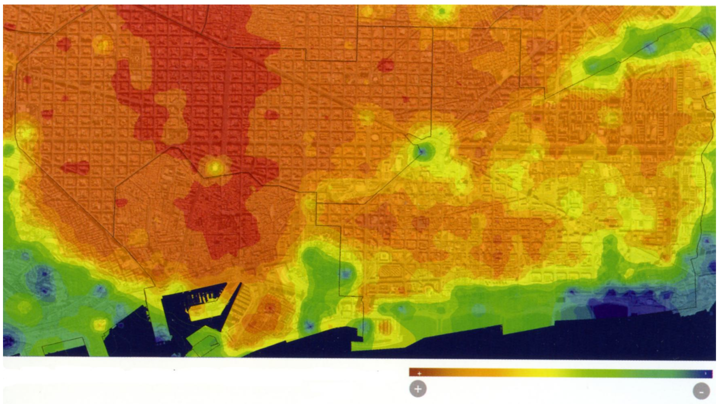

Figure4. Concentration of bits of information per individual. Agencia d'Ecologia Urbana de Barcelona.

Connectivity increases structural information. On the contrary, when an axis presents a discontinuity in the linking of activities, the fabric is simplified, showing a hole in the diversity map. This is what happens at the crossroads of the diagonals that failed to become the centre of the city. The proposed designs for the Plaça de les Glories and its surroundings were put forward on terms of continuity and resolution of the traffic, but they became a barrier in the connection of the urban diversity between the Eixample and Poblenou Eixample. Instead of being the centre of the city as Cerda planned it, it became a hole of urban simplification and not of centrality (Busquets, Corominas, 2010).

2.4 *Creative energy*

Cities are not like stones or tables: they are not closed systems that can maintain their structure without exchanges of matter and energy with the outside. They are like candles whose flame burns steadily as a result of the disequilibrium in the energy flow that sustains it. The disequilibrium of an urban system allows it to maintain a state of apparent equilibrium, that is to say, a state of stability and continuity. The closed state is unstable and fragile, because it subjects the system to the second principle of thermodynamics, which states that all structures tend to dissipate in heat and disorder. On the other hand, in whirlpools, in flames, in our bodies, and in our cities, the openness allows the components to change within the structures, which remain stable, while slowly evolving.

The resilience of fractal structures is linked to their power to complexify so as to absorb fluctuations. The model in nature is the fractality that explains the geometry of coastlines. The energy of the ocean and the incessant movement of currents and waves that keep the coastal system far from equilibrium create a constant complexification by breaking the symmetry. In return, the increasingly complex coast absorbs the movement of waves and dissipates its energy in an efficient way, self-limiting the process of erosion. We have here a natural example of non-dualist duality between form and energy where the dissipation of energy makes the forms more complex instead of destroying them and where this complexity ensures an optimal use of energy while increasing the resilience of the overall form/energy system.

3 EMERGENCE OF COMPLEXITY, EFFICIENCY AND RESILIENCE

3.1 *Exergy and emerging fractals*

Industrial ecology,[8] as developed in particular by James J. Kay, provides a conceptual framework for understanding the sequence of local and global flows. The principle of industrial ecology is to use symbioses between the different components of a system to enhance its overall efficiency. This can easily be transposed to urban systems. In this framework, Kay proposes a thermodynamic approach based on the notion of exergy.

[8] Industrial ecology is a conception of industry that regards the industrial system as an ecosystem crossed by flows of material and energy.

Exergy measures the maximum useful work that a system can draw from its available energy. Otherwise put, for a given quantity of available energy within the urban system, only a part, called exergy, is utilizable. The rest will be dissipated as heat during its transformation, thereby increasing the entropy of the system, without being useful in any way. For a given amount of energy, the bigger the exergy output, the more limited the increase of its entropy will be: the maxima of exergy output are also the minima of entropy output.

Extending Prigogine's considerations on open systems, Kay[9] shows that such a system pushed far away from thermodynamic equilibrium rejoins a stationary state of maximum exergy, that is to say, the optimal use of energy flows. This state corresponds exactly to the minimum of entropy production that Prigogine discusses. "An open system with exergy pumped into it is moved away from equilibrium, but nature resists movement away from equilibrium [...]. When the input of exergy and material pushes the system beyond a critical distance from equilibrium, the open system responds with the spontaneous emergence of new, reconfigured organized behaviour that uses the exergy to build, organize and maintain its new structure."[10]

Kay's work shows that a highly organized and highly structured system will utilize energy more efficiently than a more disordered system. A question remains: What is the best structure to give a city to maximize its efficiency as a system? The answer given by thermodynamics and Bejan's constructal theory is a fractal hierarchization, organized according to the Pareto distribution.

Bejan's constructal law[11] posits that for a flow-driven system to live and grow it must develop in a way that provides easy access to the flows running through it. Now, for systems subjected to certain types of flows, those that connect a point to a surface or a volume, Reis[12] has demonstrated the equivalence between the constructal law and the minimum entropy output predicted by Prigogine: the structures resulting from constructal theory are those that achieve the objective of maximizing exergy. For these flows, thermodynamics and constructal theory both describe the same optimal structure: a tree-like structure, with a main flow (the trunk) divided into secondary channels (the branches), which are subdivided into capillaries (twigs and leaves). Trees are fractal structures: they display the same pattern on every scale of branches dividing into smaller channels. This construction obeys scaling laws, that is to say the Pareto distribution.

3.2 *Emergence*

Emerging connective forces at all scales act on urban morphology to generate fractal structures. Emergence is the opposite of the utopian simplified orders that architects such as Le Corbusier have tried to impose on cities. Huge quantities of energy are needed in such artificial repetitive orders to maintain the urban system in a stable state. Modernist cities, with abstract giant forms imposed from the outside, obstruct the emergence of small-scale connections, whereas the continuous creation of connections in historical cities favored their evolution. The continuous fabric of traditional buildings with courtyards, because of its connective forces developing inwards, has a stabilizing impact on the urban system. Giant modernist buildings standing in loneliness isolation do not connect into the urban fabric. They have a destabilizing impact and fail to create an evolving adaptive structure. Modernist architects turned their back to the universal laws of urban evolution by working with large-scale elements only and making the urban land a blank slate devoid of the incremental successive layers of historical traces. The Utopian machinist juxtaposition of vast homogeneous zones, made of a repetition of very big objects, hinders the appearance of emerging properties that were not integrated or even forecasted or predictable into the initial framework of the system. For a property to emerge at a higher scale, smaller scales need to exist to foster its emergence. Each spatial scale supports the higher scales in the ascending hierarchy of

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[9]J.J. Kay, "On complexity theory, exergy and industrial ecology: some implications for construction ecology" in C. Kibert, J. Sendzimir and B. Guy, *Construction Ecology: Nature as the Basis for Green Buildings*, Spon Press, 2002, pp. 72-107.

[10] Ibid.

[11] A. Bejan and S. Lorente, "The constructal law of design and evolution in nature" in *Philosophical Transactions of the Royal Society B, 365*, pp. 1335-1347.

[12] A. Heitor Reis, "Constructal Theory: From Engineering to Physics, and How Flow Systems Develop Shape and Structure," *Applied Mechanics Reviews*, 59, 2006, pp. 269-282.

an emergent complex order. These emergent properties allow the system to repair, stabilize itself and to evolve.

Emergent properties are analogous to the human brain. We cannot understand them by breaking down the system and analyzing its parts. Three conditions are needed for them to appear in a system: a high connectivity, the continuous creation of new connections and a sufficiently low degree of control, since lessening control implies increasing emergence, and vice versa.

The Internet and social networks, such as Facebook or Linkedin, are ceaselessly growing and increasing constantly their connectivity, while presenting scale-free properties in the structure of their connectivity that give order to myriad of data and allow us to navigate comfortably into them. Strikingly the street patterns of cities like the ancient town of Ahmedabad and Venice share the same connective structure as social networks when streets are considered as nodes of the network and links as relation between streets. This scale-free connectivity analogous to that of a leaf provides local efficiency of the network and a local clustering of short-range connections, without hindering global efficiency of the long-range connections.

A fundamental attribute shared by resilient living cities is a high degree of scale-free complexity. The geometric and topological assemblage of elements constitutes a series of organized wholes on each successive spatial scale and across the progression of scales. This fractal harmony is what distinguishes a coherent urban composition from the repetitive serial modernist utopias. Modernist cities are incapable of generating urban coherence. Geometric and topological coherence connects the city across all scales. It is crucial to the vitality of the urban fabric and to its exergy maximization.

In a fractal morphological field, the position and the form of each element are influenced by its interaction on different scales with all other elements. When the result of all these interactions creates a form, it is neither symmetrical nor fixed. It displays a degree of plasticity that allows it to evolve. Evolution is only possible if the large scale is correctly defined on the basis of a great many connections obeying a hierarchy of scale.

What matters more than the nature of urban elements is the structure of urban connections. In a multiply connected, living organic structure, the smaller components can be changed without affecting the overall structure. Building the whole from the parts in an organic way leaves room for evolution. Starting from the whole creates structures that cannot evolve. Modifying the urban whole once it has been established from a technical blueprint involves destroying a great many components on very different scales. In a bottom up city evolving through a myriad of micro processes, it is, to the contrary, easy to modify smaller components, like the arrangement of rooms in a house or the nature of buildings along a street.

The resilience of fractal street patterns derives from a network of paths that are topologically deformable. To be resilient, urban forms must not be defined once and for all. They must include degrees of freedom, be deformable and display a high degree of plasticity. They must be capable of accompanying the torsion, extensions and compressions of paths such as the ones that have occurred in Mediterranean cities after the fall of the Roman Empire, without tearing. To be deformable, the urban fabric must be strongly connected into the smaller scales and weakly connected into the large scale. This is a characteristic of the Japanese city with its multiplicity of short-range connections and average distances between intersections of around 50 meters in Tokyo as in Kyoto.

Deformability does not mean that the initial plan must be twisted and curvilinear. Orthogonal grids, be it in Kyoto derived from a Chinese imperial capital plan, in ancient Rome urban legacy around the Mediterranean, in the Latin American gridded plans of the XVIth century prescribed by *Las Leyes de las Indias*, have shown, provided they were originally enough fine grain, a remarkable propensity to evolve towards more complex patterns. In India, the orthogonal legacy of the Hellenistic period has been filled by the fractal intricate patterns of Hindu cities and by the labyrinthine patterns of Islamic cities.

3.3 *Interfaces and exergy maximization*

The Pareto distribution and fractal structures associated with it have a unique capacity to ensure optimal efficiency of flows, which explains why they are so widely present in nature and in the structures that living organisms have selected as the most resilient over billions of years of evolution, and why they have been used to optimize industrial processes. Fractal structures are found in natural and artificial interfaces: pulmonary alveoli, plant roots, river basins, and electrodes in batteries. Large surfaces of interaction appear in fractal geometries. This is the case of systems in which either a physiological or an industrial process takes place through a membrane that must be optimized in a given volume. The geometric arrangement of alveoli in the lungs, for instance, has to be close to a fractal dimension of 3. Fractal interfaces display robust properties, which means that their performances are structural, formal, and less sensitive to variations in physical and chemical circumstances than other interfaces. This robustness explains why natural selection prefers living systems using this geometry. In cities, complex textures with courtyards and squares are what correspond to these porous membranes. Organized according to fractal scaling laws adapted to the climate, such textures optimize surfaces of heat, light, and energy exchanges, as a function of the city's bioclimatic parameters.

Thus the Pareto distribution is the universal starting point of efficiency optimization. Whether we are dealing with energy networks, flow systems, or urban textures, it alone ensures the maximization of exergy that this optimization requires.

3.4 *Self-organization, long fluctuations, and catastrophes*

Fractal structures optimize urban flows and are also vital in giving cities the resilience that they are lacking today. The more structured and complex the city, the more readily it can absorb the perturbations to which it is subjected, without letting them upset the stability of its structure. It is in assimilating the fluctuations and tensions that it complexifies. Hence, there is an ongoing dialogue between the city's capacities of resilience and the constraints to which it is subjected, between the fluctuations from the outside environment and its resistance to these fluctuations.

The resilience of a city is intrinsically linked to its self-organizing capacities. But self-organization is inevitably lodged in time, and the long span of natural fluctuations is not that of contemporary cities; the latter are designed and built very rapidly by authoritarian, rigid forms of urban planning.

Alongside long fluctuations, whose effects over centuries are sometimes imperceptible, there are short-term, even catastrophic fluctuations, which are becoming more frequent today, with their share of deaths and destructions. Cities were always subjected to them. Cases in point are the Great Fire of London in 1666 and the earthquake in Lisbon that outraged Voltaire. But London and Lisbon both managed to live through these disasters and maintain their form, whereas contemporary cities are more and more vulnerable to earthquakes, droughts, floods, and natural and energy crises. They are vulnerable, to begin with, due to their low efficiency, and their voracity in energy and resources. They are also vulnerable because they are not adapted to their sites, to the environment they inhabit all in the same way and which, from one day to the next, may violently remind them of its existence and its identity, like the Chao Phraya delta into which Bangkok is inexorably sinking. Finally, they are vulnerable because of the disordered uniformity of their urban fabric, its absence of fractal structure, of scale free connectivity based on a long history that forges a city's capacities of resilience.

4 ARBORESCENCES VERSUS LEAF STRUCTURES

Counteracting the vulnerability of contemporary cities requires a real paradigm reversal, and a shift from a mono-scale conception to a fractal conception of cities. Only fractal structures in the case of flow networks can secure optimal efficiency, while limiting the propagation of local perturbations. But another parameter is just as fundamental for the capacities of resilience of cities, and that is the fine-grained connectivity of their subjacent structures. This parameter entails pushing our thinking beyond the tree-like structures prescribed by simple thermodynamic considerations.

4.1 *From trees to leaves*

An arborescence scale hierarchy is what causes its efficiency. This then is the first element we are seeking for the sustainable structure of the urban system: a strong scale hierarchy ensuring system efficiency. However, the connectivity of a tree is low: between two points there is only one possible path. For a city to be connected, it must be structured not like a tree but like a leaf.

A series of connections whose intensity obeys a Pareto distribution increases resilience by preventing rapid and catastrophic fluctuations from spreading quickly through the system and disorganizing it. There should be few long-range connections and these connections should be weak to prevent the spread of disrupting fluctuations. Weak connections are what allow the fluctuations to be absorbed. On the other hand, a great many strong short-range connections ensure the system's deformability. If efficiency is linked to the arborescence of elements, resilience is linked to a more abstract arborescence, that of the system of connections between elements the intensities of which should also obey a Pareto distribution.

As Alexander has noted,[13] one can readily see that street networks are not structured like trees: small streets are more often linked to one another or to several higher level streets, which is not the case in a tree structure. In fact, the underlying structure of these networks is what is called a "semilattice". A striking image of this type of structure is the system of veins on the leaves of most deciduous trees. Their leaves manifest a remarkable exception to the many tree-like systems observed elsewhere in nature. They display the same scale hierarchy, which proves again the universality of the Pareto distribution, but the midsize veins and the venules connect to one another, like the streets of a city, and so the connectivity is much stronger than in a tree-like structure.

4.2 *Efficiency and resilience in semi lattice structures*

The multiple connectivity and scale hierarchy that leaves and cities have in common enhance both their efficiency and their resilience.

Firstly, the loops that these structures contain, as Francis Corson has demonstrated,[14] manage variable flows more efficiently. The tree structure is most efficient when it comes to distributing stationary flows. But one of the characteristic features of urban flows is their extreme variability, both in time and in space. The semilattice structure absorbs these variations by distributing flows along different possible paths. This is impossible in a tree-like structure, where there is only one path between two points.

Secondly, the semilattice structure imparts greater resilience to a network. When a branch of a tree is cut, all those that grew from it will die too. In a leaf, if a vein is interrupted, the redundancy of the network will allow the flow to get around the interruption via secondary paths, so that it will only be partly slowed down by the degradation of the network. This is why cities structured like leaves are more resilient. Just imagine that a path is blocked by an accident: the flow is simply deviated onto other paths to irrigate the side beyond the perturbation. A part of the leaf's network can be amputated and the leaf will go on living and converting light energy into nutrients. Thanks to the scale invariance of the Pareto distribution, nature has provided for redundancy on all scales to ensure the permanence of its structures. The simultaneous existence of small and big nervures having the same function contains a natural redundancy for living organisms that answers the objective of efficiency and resilience with an economy of volume.

5 SUPERBLOCKS: THE SUPER EXPONENTIAL COLLAPSE OF CONNECTIVITY

Historical cities have acquired over time a scale-free, multi-connected structure, like that of a leaf – a semi-lattice fractal structure. This structure connects and weaves the fabric of historical space. It contains small, narrow streets that connect to longer and wider streets that are themselves connected a few wide boulevards. This hierarchy results from the way in which such open systems far from equilibrium like cities are organized in reaction to the fluctuations of flows that run through them.

Quite the opposite, modernist cities, the archetype of which is Le Corbusier's *Radiant City*, do not provide fractal optimization. They are developed on one scale only, an inhuman scale of monotonous repetition of residential units and highways that distends and denatures the urban fabric.

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[13] Christopher Alexander, "A City is not a Tree" in *Design, 206*, 1965, pp. 46-55.

[14] Francis Corson, "Fluctuations and redundancy in optimal transport networks," *Physical Review Letters, 104*, 2010.

5.1 *Superblocks and small blocks: sizing/scaling and differentiating*

The highly complex leaf of Chinese traditional urban form has been almost completely erased during the last 30 years to be replaced by modernist cities organized by giant and simplified car oriented infrastructures. It is striking to see the correlation between the Chinese superblocks, mass developed during the last 30 years, and the under development in terms of linear density of an increasingly distended anddisconnected street network, which, despite its gigantism, fails to organize and integrate the city into a real urban fabric. The gigantic scale of the roads in Chinese cities with their giant grid of 500 meters, and the very large mesh of subways with 1.5 km between stations, channel all the flows into a few constrained large arteries. The overall connective system lacks scale-free hierarchy with a differentiation of streets according to width, span and speed. It lacks topological hierarchy and clustering around hubs. This lack of hierarchy, alternative paths and clustering, ends up in severe local and global structural inefficiencies provoking congestion. Traffic problems are made even worse by the giant dead-ends that high towers are.

Chinese urbanization for the last 30 years has been based on these superblocks and giant infrastructures. The basic unit of development has not been the highly differentiated small block of historical Chinese cities or of European and American cities cores such as Manhattan, Boston, San Francisco, and Chicago. It has been the superblock of Le Corbusier modernist theories developed one century ago around 1920 and since then strongly criticized and abandoned in Europe and the U.S.

These superblocks are oversized: 400 meters to 500 meters side (and up to 800 meters side in some districts North of Beijing) to be compared to the very small block of Tokyo (50 meters side), of the Roman city and its legacy in Italian towns and most towns around the Mediterranean (70 meters side), of Paris, London and Manhattan (120 meters side). In terms of surface one 400 meters Chinese superblock (the most usual basic unit of panning of Chinese recent developments) equals 64 Japanese blocks. It equals 32 Mediterranean Europe blocks, and 11 Manhattan, Paris, London or Hong Kong blocks.

Inside superblocks, lack of diversity is provoked by the serial repetition of the same type of buildings usually on a dozen or even several dozen of superblocks and by the lack of subdivision in plots of the superblock. By contrast Manhattan small blocks were subdivided in the original plan of the city into dozens of plots with a differentiation according to the orientation (plots along the North-South avenues had not the same size and geometry than the plots along the East-West streets) in order to encourage a specialization (businesses along the avenues and houses along the streets). The unit of development of Manhattan, London, and Paris has been the plot of about 500 m^2, each plot being developed differently by different economic actors. Thus the scale difference in the unit of city development between the Chinese superblock and the Manhattan plot is 320 fold and rises to about 3000 fold when a single developer develops 9 superblocks. The spatial land structure of Chinese contemporary developments is simply not fine grained enough to foster high levels of differentiation like in Manhattan or London.

To achieve differentiation, large and medium scale projects are of course necessary; but a long tail of small projects must complement them. In Manhattan it is possible to have on an area of 1.5 km2 (9 Chinese superblocks) a potential of 3000 different investors developing the urban fabric and the economic activities when in China a single developer develops a large scale mega project or a gated community in 9 superblocks. In Tokyo, where the plots are even smaller, the potential of differentiation and thus of resilience and adaptation, through the action of individual investors, raises 5000 fold above Chinese current practice. This highly differentiated urban fabric is at the same time more resilient and adaptive to changes (gradual or sudden). Differentiation potential is key to resilience and evolution. An undifferentiated system with only big elements, even if it covers a large territory, is only a small system inflated and its resilience and adaptive potential collapses compared to a really large system in terms of high differentiation and high number of structured interactions.

As with the 3000-fold collapse of differentiation potential, one may wonder if a collateral even stronger collapse in connectivity could not make Chinese recent development extremely weak in terms of resilience. An oversized urban fabric based on superblocks development with 3000 times less differentiation and an even stronger collapse of connections, compared with the small block urban fabric, may be equivalent structurally to a much smaller city and thus be unable to support the weight of a its mass of inhabitants. Superblocks are indeed shrinking Chinese cities when we look at them in terms of resilience. There is simply not enough structure in them to support their mass and channel their huge flows efficiently.

5.2 *Superblocks and small blocks: connecting*

The average distance between intersections is a good indication of the grain of a city. The grain of new Chinese cities (500m between intersections in average in new developments) is 7-fold coarser than the grain of Turin, Italy (70m between intersections in average), and more generally of most European or Japanese historical urban cores. There is a 4-fold increase between the grain of Paris/London/Manhattan (around 125m between intersections in average) and the grain of Beijing new developments (500m between intersections in average).

In terms of connectivity, this translates in a simplified model, comparing 100km² urban areas (Table 1).

Table 1. Comparing the number of intersections and blocks in Beijing and international cities

	Paris/London/Manhattan	Tokyo/Kyoto	Beijing
Number of blocks	6,400	40,000	400
Number of intersections	6,400	40,000	400

When comparing the number of intersections and blocks in Beijing and international cities, the difference is 100-fold with Japan, 16-fold with Europe and Manhattan. The grain of the city directly impacts on the number of available paths in the city. High numbers of possible paths avoid congestion effects in the network and increase its resilience, by providing many alternatives to go from one point to another within the city.

The number of possible paths between two locations in the city is directly related to the number of links between intersections, and is gigantic. As people act in a rational way, they tend to use the shortest path. In the following example, a person wants to travel from point A to point B in a theoretical grid of side n. Using the following grid, the distance between A and B is 2n (Figure). The number of available paths in this grid is equal to $(2n)!/(n!)^2$, that grows exponentially with n.

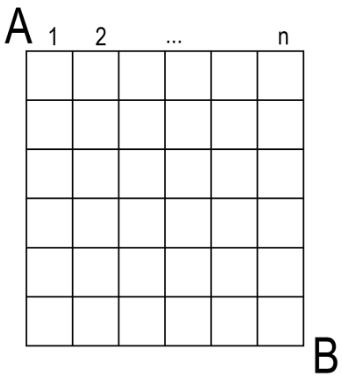

Figure 5. The distance between A and B.

Let us now compare Beijing, Paris and Tokyo on a 1km² area, point A and point B being in the opposite corners. With an average distance of 500 meters between intersections, the street network in Beijing displays in average 3 intersections for 1km. n equals 3. The number of possible paths is $6!/(3!)^2$, that is 20. With an average distance of 125 meters between intersections, the Parisian street network displays 5 intersections for 1km. n equals 5. The number of possible paths is $10!/(5!)^2$, that is 252 paths. With an average distance of 50 meters between intersections, the street network in Tokyo displays in average of 20 intersections for 1km. n equals 20. The number of possible paths is $40!/(20!)^2$, that is more than 100 billion paths!

Empirical measurements show this phenomenon on real fabric samples. They show the connectivity potential of fine grain cities like Paris or Manhattan, or of super fine grain cities such as Tokyo, which explains their resilience. To give an idea of the exponential growth of the connectivity potential: on just a square km shifting in Beijing the grain from 500 m side to 125 m side would lead to an increase of the potential paths from 20 to 252.

This abstract simplified model, which is based on the real empirical differences between Paris/London/Manhattan grain, Tokyo/Kyoto grainand Beijing grain, shows that sizing/scaling is dual to connecting and that shifting towards finer grain has exponential effects in increasing the links and thus the interactions necessary to increase the resilience of urban structures and their efficiency in maximizing exergy.

6 CONNECTING, DIFFERENTIATING AND THE MAXIMIZATION OF EXERGY

6.1 *A tale of three cities*

Three highly successful resilient cities, London, Manhattan, Tokyo, have a highly connected and highly differentiated at all scales city structure.

Manhattan grid (avenues and streets), block sizing, and parcels sizing differ according to orientation and this seems to be the minimal conditions in order to create an enormous potential of differentiation. At the global Manhattan scale, the historical preexistence of New Amsterdam (now Wall Street) at the bottom part of the city, the diagonal of Broadway (a former Indian path way), the creation of Central Park are certainly the main seeds that have pushed to the emergence of socially, functionally and even stylistically highly differentiated neighborhoods from the rather uniform Commissioners' plan of 1811. The urban fabric (physical and social) of Wall Street is totally different from the one in Soho or Tribeca or from the one in Upper East Side. Manhattan has been the receptacle of massive immigration influx from Europe and has evolved (and is still evolving) for two centuries with a constant increase in the complexity of its structure and in its differentiation. Manhattan is a fine grain "planned" city only in the design of its street patterns and of its land division into parcels. Myriads of individual initiatives have then shaped the evolving form of the city. The city results from a delicate balance of overall planning giving an overall stable and fine grain framework to a myriad of market forces.

In contrast, London is not a city planned from the beginning. It is complex, connected, and highly differentiated while being integrated. Its urban form results from a balance between history and market forces. The land division into parcels has maintained the historical continuity of the most ancient parts (and now the most modern, vibrant and bustling of economic activity) of the city. Due to the stubborn resistance of London inhabitants to planners' intentions to rebuild the city according to a "rational" orthogonal grid after the Great Fire of 1666, the city has kept in its central part, one of the most powerful financial centers in the world, its medieval street patterns. In contrast Lisbon after the earthquake of the XVIIIth century has been rebuilt according to an orthogonal grid.

Tokyo is different from both Manhattan and London. It has been shaped by topography, the differentiation created by the "empty" Imperial palace in the center, and the spiraling movement of different neighborhoods around this invisible, sacred and empty core. The Shogun original intention was to build for him a capital according to an orthogonal geomantic model like the series of Japanese Imperial capitals derived from the Chinese model. Tokyo now is a gigantic mosaic of mostly low rise and very fine grain different neighborhoods that give to their inhabitants a strong local human scale while being integrated into a whole that despite its gigantic, physical and human, scale manifests a kind of complex integrated order. With its 37 million inhabitants, Tokyo, the largest city in the world since 1980, has succeeded to create a subtle order and sense of place both at the very local and at the very global scale.

6.2 *Five strategies for fostering the emergence of exergy efficient urban structures*

Despite their differences, what is common in London, Manhattan, Tokyo, three resilient cities that have lasted centuries and have all succeeded to be the economic dominant world city at different moments in history? Can we find in their urban form common features that explain why they have been extremely resilient, have organized the planet around them and have derived the maximum benefits of agglomeration economies? In return, how market forces have shaped them in the sense of a successful differentiation? What lessons can we derive from their success, to define strategies for increasing the resilience of cities?

6.2.1 *Wholeness*

These three cities are extremely complex wholes that present a pervasive and elusive sense of unity and uniqueness. Despite their extreme diversity, they have an immediately recognizable unity: you cannot mistake Tokyo with London or Manhattan and even with another Japanese city like Osaka. At all scales (street, neighborhood, district, city) they provide a sense of belonging to an identifiable whole. Each scale is well defined and smoothly integrated to the upper scales, delivering constantly through the different scales a strong sense of place.

6.2.2 *Diversity*

The amount of diversity inside this complex unity is enormous. This diversity has been created by history and by myriads of different sizes initiatives along a long period of time. Not a single brownstone house is exactly identical to the other in Manhattan Upper East Side. Along Central park on Fifth Avenue, the Museum mile and the wealthy mansions stand in strong contrast to the quieter inside the street brownstone houses.

6.2.3 *The "signature" of complexity*

The relations between the human scale and the city scale, between the diversity and the unity, between the local and the global, between the "small" and the "large", between the "units" and the "whole", are not random relations. They show the "signature" of complexity, that is the typical structure of complex systems that have evolved for billions of years like life or just for decades like the internet and social networks and have survived, prospered and colonized the Earth thanks to their high efficiency, resilience and adaptive qualities. All these complex structures, organic or artificial and man made, share the same property: they are scale free, meaning that when we look at them at different scales they show the same amount of complexity and structure. When we look at a district in Paris or Manhattan, for example, we find the same relative distribution of large public parks, medium scale and pocket parks smaller than half hectare, than in the whole city. Each district is a reduced scale version of the city for the relative distribution of sizes of amenities such as public parks, health, education, and shops. When we look at the distribution of sizes of streets in Paris, we find at city scale and at district scale the same blend of 20 meters wide boulevards, 12 meters wide streets, 10 meters wide, and 8 meters wide. Each sub pattern of streets at neighborhood and district scales presents the same distribution properties as the whole city.

6.2.4 *Connectedness*

All three cities are extremely well connected at all intra-urban scales. This connectivity also is not random connectivity: it exhibits properties of highly efficient networks. Here again a structure emerges that unites many different fields from economy to engineering to social networks. This structure is scale free in the structure of its relations. In a network, what is even more important than geometry is topology, that is the structure of relations.

Networks can be described as nodes (for example subway stations or people on Facebook in a social network) and links between nodes. The degree of a node is its number of its links, for example the number of links between a subway station and its neighboring stations, the number of your friends on Facebook or Linkedin.

Here the analogy between the networks of our three successful cities is with the success of social networks. A social network like Facebook is scale free: any sub-network at all scales has the same structure as the whole network. For example the sub-network of people living in Soho shows the same structure as the sub-network of Manhattan, which shows the same structure as the sub-network of New York, which shows the same structure as the sub-network of the East Coast, which shows the same structure as the sub-network of the U.S., which shows the same structure as the sub-network of the world Facebook.

Social networks as well as street networks in complex evolved cities show other interesting characteristics that are summarized in the term of "small world" properties. In particular they show a high level of clustering, meaning that neighboring nodes are also linked in a high proportion. In simple terms, clustering means that there is a high probability that your friends on Linkedin be friends or become friends in between themselves, creating a "small world" that is in return connected by hubs to other "small worlds". This property has made the success of social networks on the Internet and interestingly is the way airlines have organized the traffic with continental hubs to minimize their cost and maximize their routes and economic efficiency. It can be shown that complex evolved street patterns show this small world property when a street is considered as a node and its intersection with another street as a link. Complex subway systems, such as the ones in Tokyo, London, Manhattan, tend to evolve with a long time and multiple decisions towards the same structure as social networks. From the "small world" properties a number of measures of efficiency can be derived such as characteristic path length, global and local efficiencies.

6.2.5 *Continuity at human scale*

Fifth, all three cities show local human scale, made of continuity and closeness of a fine grain built urban fabric, diversified in its functions, with a well-sized and continuous public space. Density matters but Manhattan, London and Tokyo show different built densities from high in Manhattan (although not significantly higher than 7 floor high Paris despite some vertical parts) to medium in London, and in most parts of Tokyo made of a continuous fabric of small 2 floor individual houses. Verticality is not density and interestingly even a city where verticality is very well planned in a fine mesh of 30 meters wide avenues and 20 meters wide streets has a demographic density almost identical to that of Paris (24 000 people/m^2) and only 50% higher than that of Seoul or Tokyo. Yet what matters more than density and is common to these cities is continuity, fine grain diversity and human scale.

7 CONCLUSION: A CITY IS NOT A MACHINE

By their openness to the environment and the productive disequilibrium created by the incessant activity of people and transformations of societies, cities exhibit a profoundly different nature and logic than machines. Cities are not artefacts; they are living organisms that are born, grow, age, and die. The organization of cities cannot be understood from the same perspective as artificial machines. Cities, like life itself, but unlike machines, have an aptitude to create complexity according to a much more complex logic than that of an artificial machine. At the heart of this ability is the phenomenon of self-organization[15] provoked by exergy maximization in an open system far from the equilibrium.This phenomenon accounts for theadaptive capacities of life and cities.

"The *artefact* machine components are extremely reliable," EdgarMorin writes, "but the machine as a whole is much less reliable than its individual components. All it takes is an alteration in one of its components for the system as a whole to block and break down, and then it can only be repaired by external intervention. In contrast, the components of the living (self-organizing) machine are not very reliable because molecules degrade very quickly, and all organs are, of course, made of molecules; moreover, in an organism, molecules, like cells, die and are renewed, but the organism remains identical to itself, even when all its components have been renewed. So in diametrical opposition to the artificial machine, the system is reliable while its components are not."[16]

Cities share the self-organizing character of living organisms. Just look at the way Rome morphed from a Roman grid over the course of two thousand five hundred years to see the extent to which a city can be at once the same and different, and recreate the material and in part the form of all its elements over time.

Self-organization also shows that there is a *consubstantial relationship between disorganization and complex organization*. To quote Edgar Morin again, "the phenomenon of disorganization (entropy) continues its course in the living, even more rapidly than in the artificial machine, but it is inseparable from the phenomenon of organization (negentropy). This then is the fundamental link between entropy and negentropy, which are by no means two opposing entities. In

[15] The theory of self-organization has two starting points: firstly, Schrödinger in 1945 set forward the paradox of the organization of living systems that does not seem to conform to the law of thermodynamics alone; next, Von Neumann lodged the paradox in the difference between living (self-organizing) machines and artificial (simply organized) machines or *artefacts*.

[16] Edgar Morin, *Introduction à la penséecomplexe*, 1990, p. 43-44.

other words, there is a much closer, deeper link between life and death than metaphysics ever imagined."[17]

The entropy of cities tends to ruin their organization, but paradoxically they can only grow and become more complex in an organic way out of disorder, or rather, to borrow Von Foester's term, out of the "noise" in the information. This paradoxical basis of self-organization is absolutely general and cities are but a particular example of living systems. Thus, ignoring or repressing the element of disorder and spontaneity in urban life, and replacing it, as Le Corbusier did, by a mechanistic view, frozen for all eternity, amounts to condemning the city to the death of artefacts, for nothing lives that is not constantly dying to renew itself.

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[17] Ibid.

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Sustainable tall building and Vertical compact city

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ABSTRACT: From the 20th century, Eco cities have emerged in neighboring large cities in order to protect the environment and cities have been designed to use eco-friendly energies. But this Urban sprawl gave rise to inefficiency of land use and exponential energy consumption, thereby resulting in not only environmental degradation but also social disconnection of communication and dialogue. Thus, the direction of cities in the 21th century is reset toward Compact city and this has developed into a very concrete concept of Sustainable Compact City. This compact city avoids external sprawl. This Sustainable Compact City is ultimately designed to 1) reduce urban energy consumption to combat global warming and 2) revive traditional large cities by reducing suburbanization.

1 THE DEVELOPMENT OF CITY STRUCTURE

1.1 *The growth and environmental problems of cities)*

The development of modern industrial society and cities has been made in a full swing after the industrial revolution which took place in most of the western developed nations. Due to this development, the conventional agrarian society has transformed into industrial cities. During this transition, cities grew at a faster pace as much population moved to new industrial regions and cities have been covered with concrete buildings and asphalt roads as a result of the increase in traffic between cities. This development of industrial society and urbanization has led to subsequent economic growth and the development of materialistic social specialization, but at the same time urban society has engendered lots of problems.

While growth-driven cities become huge, much population has concentrated on limited areas because city growth has its own limits. Accordingly, the problem regarding the supply of houses for accommodation has arisen and the quality of the air and water has become poorer due to industrial activities. In addition, air pollution has deteriorated due to the greenhouse effects from the development of the existing Greenfield. In other words, while modern cities made use of more fuels and energy sources to produce more goods and make people consume more, there was more environmental degradation and more natural resources were depleted. Furthermore, during the process of production and consumption, more wastes were released, damaging urban environment significantly (Ng, 2010).

1.2 *Eco City for addressing urban problems*

The most serious one out of urban problems is environmental pollution. That’s because pollution is the most fundamental problem posing a grave threat to not only cities and one nation but also the earth, the living place for mankind. Thus, poor environment in large cities has been seen around satellite cities surrounding large cities such as Fig.1(a). This has led to horizontal expansion of another city like heat islands. So, from the 20th century, Eco cities have emerged in neighboring large cities in order to protect the environment and cities have been designed to use eco-friendly energies so that cities don't release pollutants and less carbon dioxide, the culprit of the global warming, is emitted. (Fig.1(b)). However, lots of construction costs were spent for electricity and the development of roads, water supply and drainage system so as to maintain these eco cities. Besides, transportation burden was created for the purpose of connection between eco cities and large cities such as logistics, hospitals and schools. This was related to demand for excessive energy and imposed more burden on the environment. Urban sprawl gave rise to inefficiency of land use and exponential energy consumption, thereby resulting in not only environmental degradation but also social disconnection of communication and dialogue. It means cities could no longer become sustainable ones (Shin, 2012)

The concept of sustainable cities is not merely related to the environment in light of city development or harmonization of development and the environment. Rather, it is an attempt to draw the attention toward the environment and development for a better quality of living for the current and the next generation. Thus sustainable cities define sustainable urban behavior to enhance quality of human living with reducing environmental load as shown in Fig. 2. This is based on the spirit of UN Conference on Environment and Development held in Rio, Brazil, 1992 (UNCED, 1992).

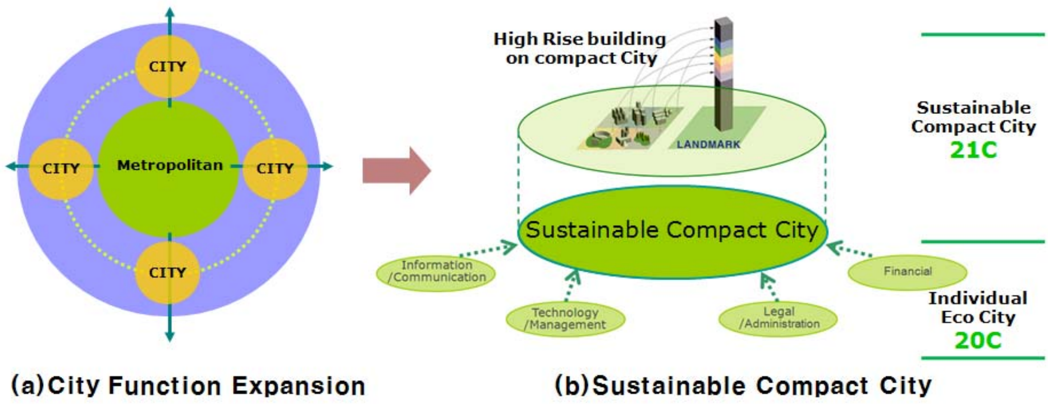


Figure 1. City Development Process (CTBUH, 2013)

Figure 2 Sustainable urban design concept

1.3 *Sustainable Compact City*

Thus, the direction of cities in the 21th century is reset toward Compact city and this has developed into a very concrete concept of Sustainable Compact City(see Fig.3.). The concept of "sustainable" means that as shown in Table 1, a city value structure for sustainable environment in the next generation focuses on the earth's environment from previous efficiency, the development of compact city from previous facility-oriented urban structure. Among them, Compact city avoids external sprawl. Instead, it builds super tall buildings in urban areas where life infrastructure such as public transportation is well in place, reducing social costs and upgrading living standards. (see Fig.1(b)) This kind of development model comes from the United States' large cities and has been recognized as the most feasible alternative in city development. The center in cities is packed with super tall buildings and 50% out of the rest of the area is green zone where ecological pillar is set, which is the characteristics of Sustainable Compact City as shown in Table 2.

Figure 3 City Concept Transition

Table 1. The Change in Urban Space Structure in the 21th Century

구 분	City In the past	Future sustainable compact city
Urban space structure	single-functional city	multi-functional city
	two-dimensional (horizontal) expansion - driven city development (growth first)	Three dimensional (vertical) network type focusing on environmental capacity (qualitative improvement)
	single-functional space	complex, multi-functional space
	Workplace-Residence Separation	closeness between workplace and residence, function composition, enhanced convenience
	facility-oriented city development	compact city establishment
	centralized metropolitan transportation system	Radiantly circulating transportation system

Table 2. Characteristics of Sustainable Compact city

Urban density	Urban concentration, decentralized concentration, high-density architecture
Land use	Land use for multiple purposes, Green zone and open space, Closeness between workplace and residence, (High Land Intensity)
Transportation	Easy access to public transportation Low usage of vehicles.
Social effect	Improved fairness, Living closer together offers the advantages of urban life, Social vitality, Open space and view
Economic effect	Self-sufficient, Cost effective infrastructure, Less Life Cycle Cost (LCC)
Environmental effect	Lower environmental degradation, Energy conservation

This Sustainable Compact City is ultimately designed to 1) reduce urban energy consumption to combat global warming and 2) revive traditional large cities by reducing suburbanization (IBEC, 2002).

For sustainable compact city, super tall buildings are considered as the best solution because as shown in Fig.1(b), super tall buildings can concentrate numerous functions of the city into one area, which is the strong point. Namely, super tall building improves land use efficiency in urban centers and encourages eco-friendly land use by securing open space and public space for pedestrians within the city. Plus, super tall building plays a vital role in creating energy and resource-conservative urban structure by closely connecting workplaces and residence through public transportation.

2 THE ADVANCEMENT OF SUPER TALL BUILDING.

- The shift of locations of super tall buildings; from North America to Asia
- The shift in terms of building use; office to mixed and other uses such as residential
- The shift in terms of principal structural materials; from all steel structures to composite or RC structures

As shown in Table 3 Super tall building has been in fashion on three occasions so far. The first was in 1930 when empire state building was constructed. The second was in the 1970s when World Trade Center and Sears Tower were built. Finally Burj Khalifa was constructed in 2010, Dubai. As shown in Fig.4, in super tall buildings, the height has been increasing for the past 12-13 years since 2000 and four ultra super tall buildings whose height exceeds 1,000m are under construction.

Table 3 (part 1). 2013 World Scyscrappers (SimArt, 2013)

Building name	Rank	Location	Floors	Hight (m)	Year Com-pleted
Burj Khalifa	1	Dubai	163	828	2010
Shanghai Tower	2	Shanghai	121	632	2014
Makkah Clock Royal Tower [Abraj Al Bait]	3	Makkah	120	601	2012
Ona World Trade Center [New World Trade Center]	4	New York City	104	541	2013
Taipei 101	5	Taipei	101	509	2004
Shanghai World Financial Center	6	Shanghai	101	492	2008
International Commerce Centre [Union Square]	7	Hong Kong	118	484	2010
Petronas Tower 1 [Petronas Towers]	8	Kuala Lumpur	88	452	1998
Petronas Tower 2 [Petronas Towers]	9	Kuala Lumpur	88	452	1998
Zifeng Tower	10	Nanjing	66	450	2010
Willis Tower	11	Chicago	108	442	1974
KK100	12	Shenzhen	100	442	2011
Guangzhow International Finance Center [Guangzhow Twin Towers]	13	Guangzhou	103	438	2010
Jin Mao Tower	14	Shanghai	88	421	1999
Two International Finance Centre [International Finance Centre]	15	Hong Kong	88	415	2003
Trump International Hotel & Tower	16	Chicago	92	415	2009
Princess Tower	17	Dubai	107	414	2012
Al Hamra Tower	18	Kuwait City	80	412	2011
23Marina	19	Dubai	89	395	2012
CITIC Plaza [CITIC Plaza]	20	Guangzhou	80	391	1997
Shun Hing Square [Shun Hing Square]	21	Shenzhen	69	384	1996
The Domain [Central Market]	22	Abu Dhabi	88	382	2013
Empire State Building	23	New York City	102	381	1931
Elite Residence	24	Dubai	91	380	2012
Central Plaza	25	Hong Kong	78	374	1992
Bnak of Chian Tower	26	Hong Kong	70	367	1990
Bank of America Tower	27	New York City	58	366	2009
Almas Tower	28	Dubai	68	363	2009
The Pinnacle	29	Guangzhou	60	360	2012
JW Marriott Marquis Dubai 1 [JW Marriott Marquis Dubai]	30	Dubai	77	355	2012
JW Marriott Marquis Dubai 2 [JW Marriott Marquis Dubai]	31	Dubai	77	355	2014
Emirates Office Tower [Emirates Towers]	32	Dubai	54	355	2000

Table 3 (part 2). 2013 World Scyscrappers (SimArt, 2013)

Tuntex Scy Tower	33	Kaohsiung City	85	348	1997
Aon Center	34	Chicago	83	346	1973
The Center	35	Hong Kong	73	346	1998
The Torch	36	Dubai	84	345	2011
John Hancock Center	37	Chicago	100	344	1969

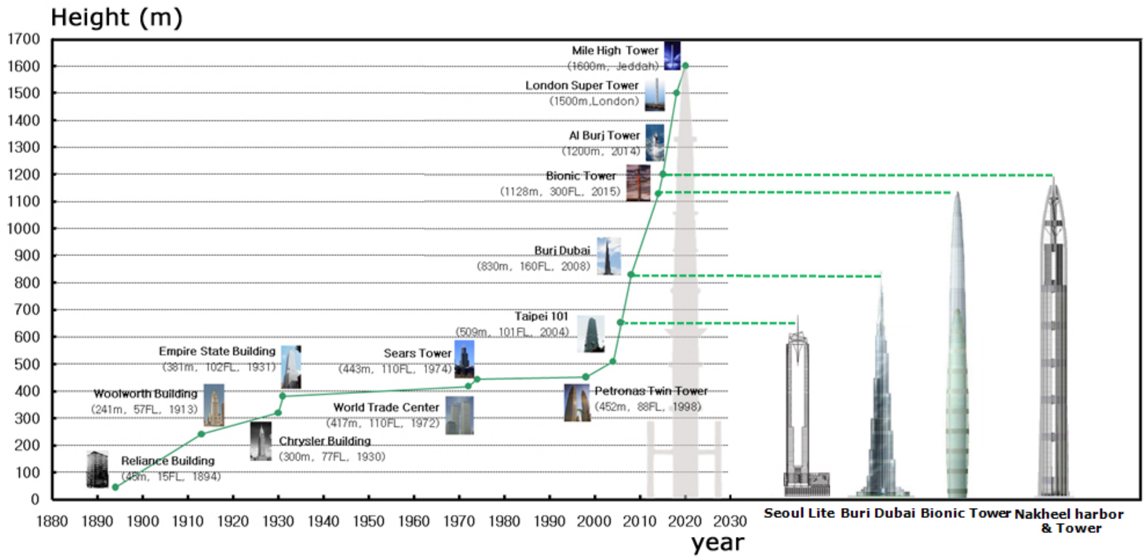


Figure 4. Global Trend and Plans of Super Tall Building (Ng, 2010).

The construction area of super tall building reflects the function and the trend of that time. Whereas the construction of super tall building centered on the United States in the past as seen in Table 4, in modern times, the construction of high-rises is prevalent in Asia and the Middle East. In addition, major materials for structure have changed from steel to concrete like in Fig.5 and multi-functional structure like in Table 5. The most significant change is that while in the past the impact of super tall building on cities as individual projects was not considered significant such as Empire State building or Sears Tower, the recent construction of high-rises such as Taipei 101 and Burj Dubai is underway as regional projects representing cities. This trend is advancing as high-rise construction reflecting sustainability which is a buzzword around the globe.

Table 4. Buildings over 150m shown according to location (Binder, 2008)

	1980	1995	2008 Plus Those Under construction	Those Under Construction Only
Americas	84.9 %	64.5 %	27.7 %	18.4 %
Asia/Oceania	9.9 %	31.2 %	59.0 %	54.5 %
Middle East	0.0 %	0.1 %	9.8 %	23.0 %
Africa	4.3 %	3.7 %	3.3 %	3.3 %
Total number of buildings	324	820	2922	877

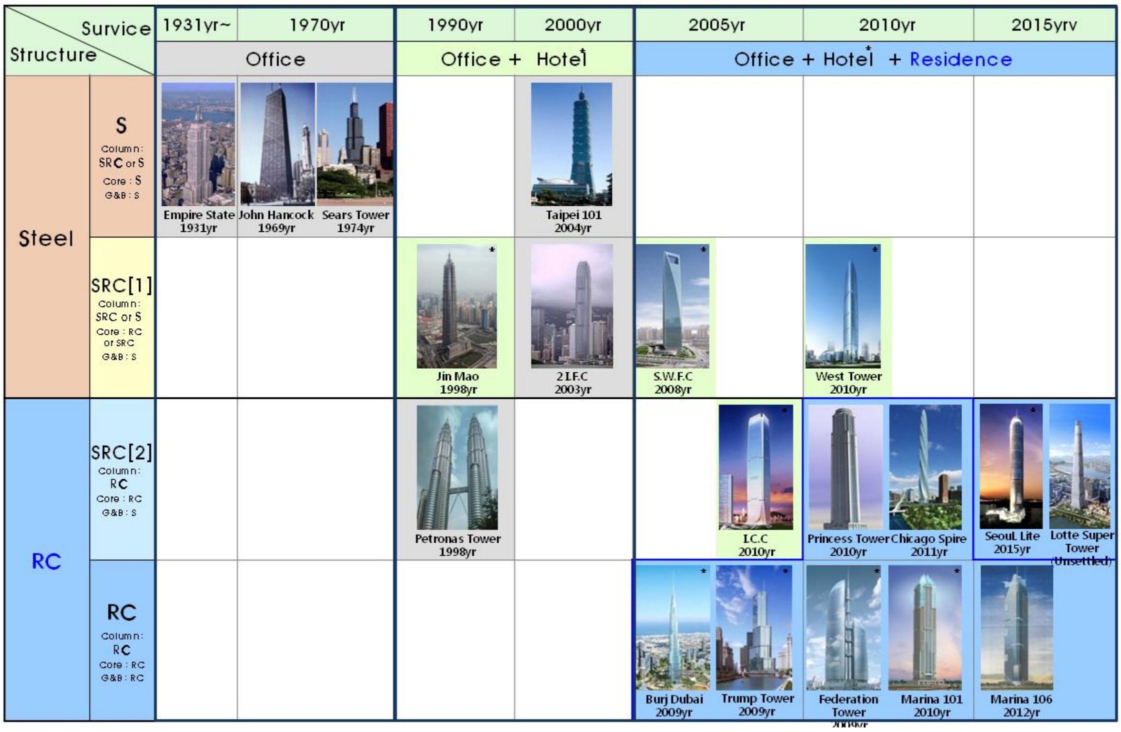


Figure 5. Trend Change of Super Tall Building

Table 5. Buildings over 150m shown according to building use (IBEC, 2002)

	1980	1995	2008 Plus Those Under construction	Those Under Construction Only
Office	84.7%	78.3%	47.3%	26.8%
Mixed-use	5.2%	6.6%	11%	17.7%
Residential	5.2%	9.6%	35.3%	47.3%
Hotel	4.9%	5.5%	6.4%	8.2%

3 COMPACT CITY AND SUPER TALL BUILDINGS

3.1 *Sustainable Compact City utilizing Super Tall Building*

- Sustainability : concept balanced between environmental, economic, and social issues
- Example : Europe(ESSD), US(Growth management or smart growth)
- Sustainable super tall building doesn't release pollutants destroying the environment

Today's main theme in urban planning around the world is sustainability. Sustainability refers to a concept that comprehensively contains environmental, economical and social implication for intergenerational equity. In Europe, it is known as ESSD (Environmentally Sound and Sustainable Development, as growth management or smart growth in the United States.

Therefore, it is necessary more than ever to establish urban development strategies that recycle infinite land resources, improve efficiency and eco-friendliness of land use, reduce transportation and infrastructure cost, curb fossil fuel use and minimize damage on the environment and landscape. As one way to implement these strategies, a new standpoint is emerging as a means to pursue selective and focused development of high-rise·high-density away from polarized value assessment of either interest in development density or height, or, high-rise · high-density or low-rise · low-density. Sustainable super tall building doesn't release pollutants destroying the environment like the air, land and water. Furthermore, it lessens environment load making economic life possible and contribute to the community. The expansion-oriented industrialized large cities are adopting compact urban concept for sustainability and one of the most effective ways is to build sustainable super tall buildings through which already many nations are enhancing their urban and national competitiveness.

Another is the efficiency of sustainable super tall buildings in terms of the environment, society and the economy. Super tall building lessens environment load and establishes social and economic sustainability as well as efforts to build a new dimension of artistic and cultural sustainable high-rises through design multiplicity.

3.2 *Benefits of sustainable super tall building*

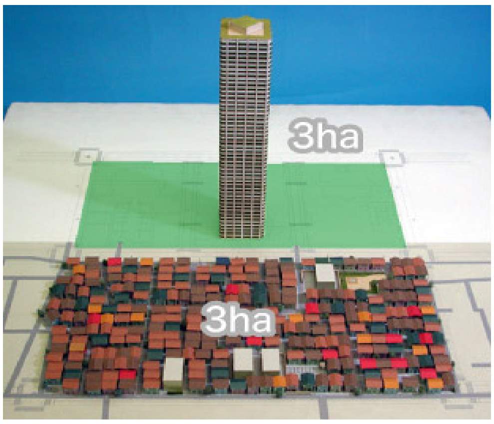
1) Efficiency of the economy and land use
- Re-use of land resources and protection of environment
- 24 hours usage of land through complex use
- A huge potential to create diverse and new economic added values

As for land use, super tall building boosts the merit of compact city as seen in Fig. 6 as it is developed with high-density in urban areas whose land prices are high.

Efficient land use doesn't not necessarily mean high-rise · high-density use of land in anywhere without any condition. According to the economic theory, in an area where there is more demand for land and accordingly high prices, high-rise · high density land use is required. On the other hand, in areas where there is more supply than demand for land and low price, it's better to use land based on low-rise and low density. Land prices are indicators showing relative scarcity of land resources in the market. So, high land prices mean that land should be used more economically because available lend is limited. In areas whose prices are high, land should be used more intensively by increasing the input of relatively low-priced resources (buildings) compared to the land. On the contrary, low land prices imply that land can be used with more capacity so that in these areas, use should be used extensively by increasing the input of relatively low-priced land compared to other resources (buildings) (Choi, 2007).

Besides, places with high land prices do not limit their use of land only during the daytime or night hours focusing on the 'time' concept but make full use of land which is known as round-o'clock occupancy. For 24-hour land use, land should be used through MXD(Mixed Use Development), not for a single purpose. In this regard, super tall building is effective in dimensionally and vertically integrating various kinds of uses such as business, commerce, residence, accommodation, entertainment and culture. Plus, land resource can continue to be utilized at any time- day (business and commerce) and night (residence, accommodation, entertainment). After all, super tall building not only increases the 'intensity' of land use but also pursues multiple uses so that economic efficiency of land use can be improved. (see Figure 7)

In addition, dimensional and multiple use of land through super tall building has a huge potential to create diverse and new economic added values. The dimensional use of land increases urban brand value with landmark effect and finally it can attract more tourists as well as local residents. The multiple use of land prevents cities from becoming hollow because distance between workplace and residence is close, and also encourage diverse night activities revitalizing the local economy.



800m2 x 50 floors x 75% = 30,000m2 = 3ha

100m2 x 300 houses = 30,000m2 = 3ha

(1ha = 10,000m2)

Figure 6. Efficiency of land use with super tall buildings in compact city (Mori, 2008)

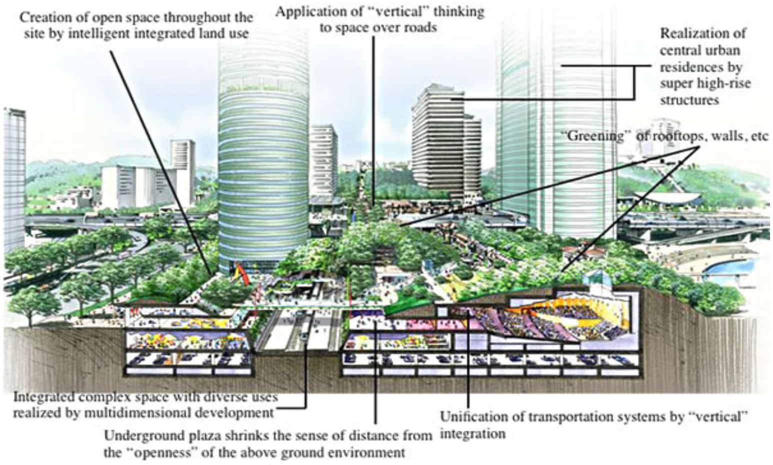


Figure 7. Vertical cities for multiple uses (Binder, 2008)

2) Benefits of transportation and social economic costs reduction.
- Energy saving and reduction of environment cost (air pollution)
- Creation of economic added value by three dimensional·complex usage
- Reduction of traffic expense
- Life Cycle Cost (LCC) less

Transportation and environmental costs reduce since cities can prevent extensive sprawl because there are super tall buildings in the center of the area from urban space structure perspective. When cities are expanded outside so that place for business and residence is separated, there will be heavy traffic on the road. In addition, the environmental costs will rise considerably because more vehicles accounting for 85% of the air pollution give off exhaust gas on the road. Therefore, dimensional and multiple use of land with super tall buildings in the center provide one-stop serve for various purposes such as business, commerce, entertainment and culture within the reach of public transportation, encouraging public transportation use and thereby reducing the use of cars. By encouraging public transportation, cities don't need to secure parking lots for cars and reduce transportation costs stemming from traffic congestion. Furthermore, cities can conserve energy and lessen the air pollution because they use less fossil fuel energy.

Lastly, there are energy conservation systems utilizing eco-friendly energy like BIPV System (Building Integrated Photovoltaic), Double Skin System and Wind Turbine System. Making full use of these systems can save energy several times more. Then the total life cycle cost (LCC) of super tall building become less than conventional low rise building.

3) Urban environmental benefits
- Reduction of infrastructure expense
- Supply of ground and vertical open space
- Secure city view's sense of freedom

It is necessary to secure more open space in order to improve urban environment in urban centers where there are many buildings. Super tall building has a positive effect on securing such open space and protecting the environment. Building high-rises by reducing the building-to-land ratio and applying the same floor area ratio can create more open space. Super tall building plays a positive role from the environmental perspective in that high-density development of brownfield and the reduction of new development field can prevent urban sprawl and protect green land or arable land (see Fig.5). In terms of open space, super tall building also supply vertical urban void as shown in Fig, 8, Seoul, Korea.

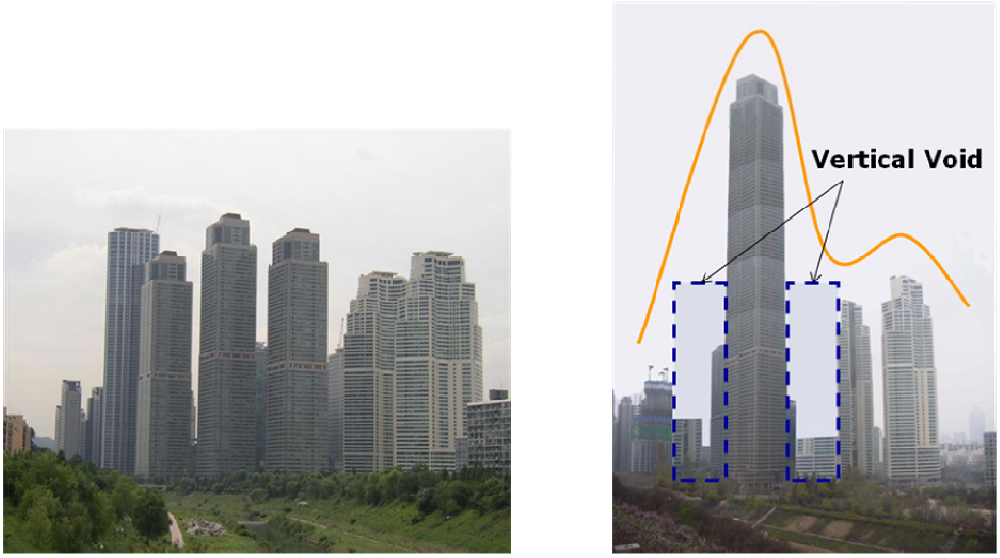


Figure 8. Super tall buildings vertical open space case, Seoul, Korea.

In this sense, super tall building becomes an effective means to improve the quality of public space by securing more idle space in the urban center.

On top of that, super tall building can reduce infrastructure costs because infrastructure including transportation such as subway and water supply and drainage system is already well in place. In other words, it is economically more cost effective to fix, expand and re-use the existing facilities than to create and provide a new infrastructure in the outer space of the cities. It easily brings about sustainable urban development.

Last, considering the eye level of pedestrians, additional increase of buildings' height has little marginal effect on pedestrians' closed views or feeling in the enter where there are already many high-rises. Rather, given humans' purview, it is better to control the width of buildings not the height which is already beyond human scale. It is important to secure visual openness between buildings by constructing more tower-shaped buildings rather than box-shaped ones or to secure vertical public space by opening lower floors as shown in Fig. 9. Aside from that, sustainable super tall building can contribute to improving the quality of urban outer space by securing a certain open space between buildings, which is in particular true with mid-upper floors of buildings. Super tall building provides more vertical void for the entire city in the same floor space index than mid-rise buildings so that there is more view corridor and circulating urban air through more wind road (Yeo, 2012).

Figure 9. Singapore city Super Tall Building for vertical public space (Choi, 2007).

4 SUSTAINABLE SUPER TALL BUILDING TECHNOLOGY AND EXAMPLES

4.1 *Sustainable super tall building technology*

Super tall building itself is not environmentally-friendly and there has been much criticism over the sustainability. Aside from increasing construction costs, super tall building requires much energy consumption. This is because the upper floor of the buildings has different weather condition like a strong wind. As a result, in order to make the inside of the buildings similar to the ground floor, HVAC is required, which consumes lots of energy and increases maintenance cost. Due to the nature of closed outside structure, buildings depend on machines for ventilation, undermining living condition.

Hence, lately, there are innovative technological developments that tackle the problems like undermined living condition in super tall buildings and minimize energy consumption. Plus, the attention on sustainability in super tall building is high, away from simple competition in height.

This trend is fully reflected in the recently held special session (UIA, 2008) on Tall Building and Sustainability in the 23th UIA World Congress in Torino, Italy during June-July in 2006 and “Tall & Green: Typology for a sustainable urban future” (CHBUH, 2008a), the theme of CTBUH 2008 international conference. Super tall building shifts its focus from the competition in height to design variables utilizing BIM and low-energy technology, and also include the following technological elements.

The following is the relation between energy consumption and the increase in mass and height of building structures and suggests a variety of systems to address the problems.

4.1.1 *Energy Consumption Characteristics with Building Scale*

1) Area

Figure 10 shows America’s commercial buildings’ energy consumption in 2003 by the scale of the building. It is noted that even though floors are limited, the more building floor space increases, the more fuel consumption rises. And, as the height of the buildings rises, energy consumption per unit space increases as follows (EIAUS, 2006).

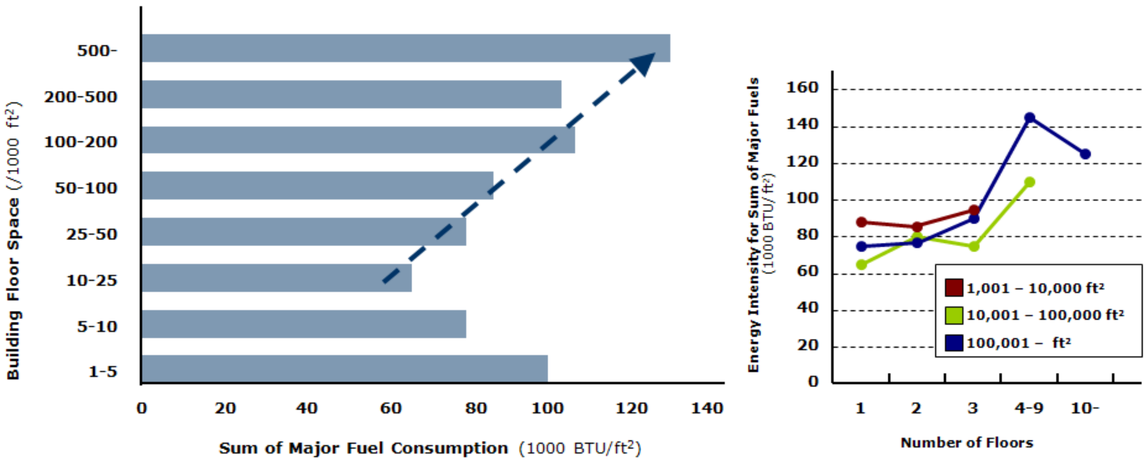


Figure 10. Consumption patter based on buildings’ type

2) Mass

Figure 11 is a study result on the correlation between the scale of buildings and energy consumption. The study was carried out on buildings in China by Building Energy Research Center of TsinghuaHua University and shows that larger buildings require more energy (BERCTU, 2010).

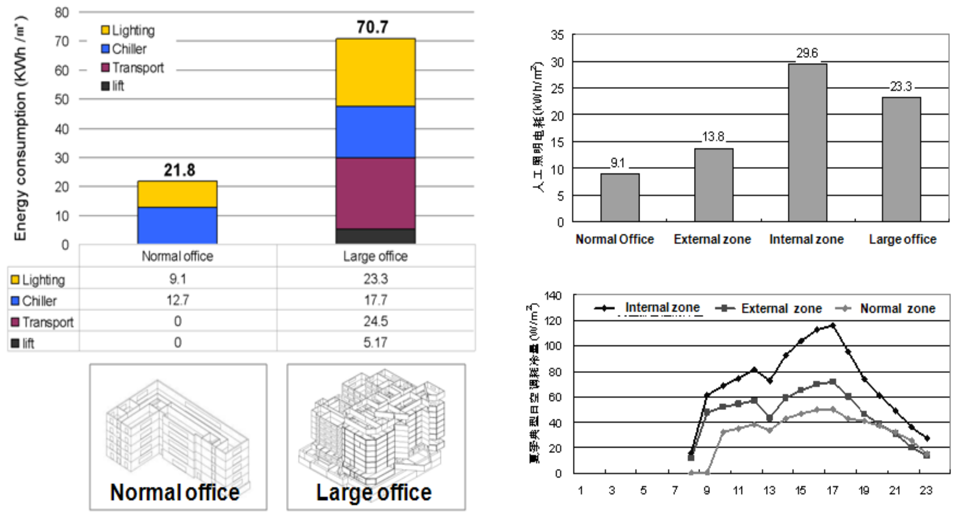


Figure 11. The ratio of energy consumption in large buildings.

4.1.2 *Energy Saving Technology of Sustainable Tall Building*

1) BIPV System (Building Integrated Photovoltaic)

There has been much development designed to take advantage of solar energy recently, among which technology development is ongoing for various designs in sustainable super tall buildings. In super tall buildings, BIPV system is used to utilize solar energy. High-rises are better to use the solar energy because they have more space to absorb the sun light compared to other buildings. Furthermore, as shown Fig.12, various designs can be applied by increasing the exterior size of the buildings for photovoltaic solar energy. BIPV panel can be applied with various kinds of colors and solar chip the sun reflects. As shown Fig.12, flexible BIPV system utilizing diverse designs is actively introduced (Pank et al. 2002).

- BIPV Systems contribute to the electronic energy supply of buildings themselves
- BIPV provides an opportunity for a clear path of direct sunlight
- Enough area to install PV panel
- Easy use to Super Tall Building
- Natural ventilation
- Improve energy efficiency and Good for health
- Economical efficiency
- Initial investment increases 8.5 % and Energy Consumption decreases 40 %
- Low LCC (Life Cycle Cost) required

Figure 12. BIPV System with Design Variation on Super Tall Building

2) Double Skin System

Double Skin System not only enhances energy efficiency with natural ventilation as its basic system but also is good for health. Also, it is very economical in terms of energy consumption – at first system increases the initial construction cost by 8.5%, but finally energy consumption drops by 40%, the system having low life cycle cost.(see Fig.13)

Figure 13. Double Skin System design Concept and Cases

3) Wind Turbine System

People have negative views on super tall buildings because they believe super tall building requires excessive energy. However, these days, wind turbine is installed on top of the building or in the middle of the building to adapt to and use natural wind as major alternative energy source.(Fig.14) Lately, like Seoul lite project(Seoul, Korea), system using the rising current of the air from the middle and lower part is being developed.

- Aerodynamic modeling is used to determine the optimum tower height, control systems, number of blades, and blade shape.

Figure 14. Wind Turbine System Cases

4) Rain Water Recycling System

As power and water consumption increases in super tall buildings, except water people drink or use to wash, purified through the sand and filter is stored in tanks and used. It can conserve water energy and recently system purifying waste water is developed with waste water disposal facility. (See Fig.15)

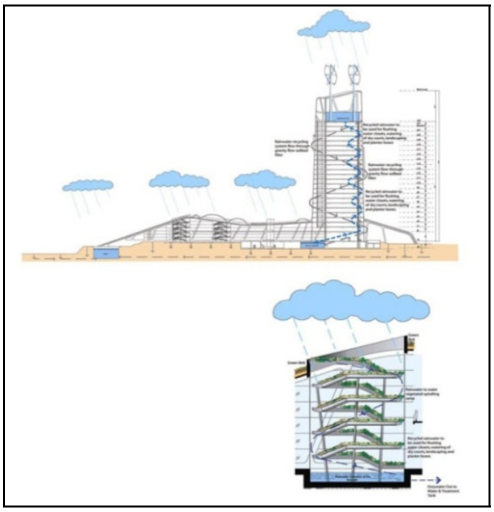


Figure 15. Rain Water Recycling and Collection Concept (CTBUH, 2008b)

5) Geothermal Energy System

Geothermal energy system uses geothermal power to get energy for heating and is mainly applied in areas with lots of geothermal energy or landfills. In the near future, geothermal energy will be more used because it is environmentally friendly energy source like solar power and wind. A case in point of geothermal energy use is Seoul lite and Shanghai tower. (see Fig.16)

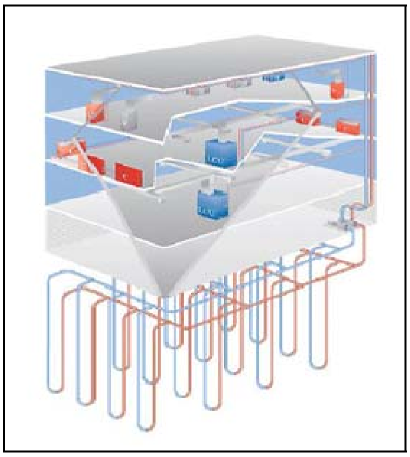


Fig. 16. Geothermal Energy System (Choi, 2012).

6) Passive daylighting System

Daylighting system is easily used co-friendly energy source. It was used in the past but due to the color change of indoor finish materials and glaring effect, the popularity declined. However, recently the system is re-emerging as eco-friendly policies are implemented to tackle the environment and energy problems.

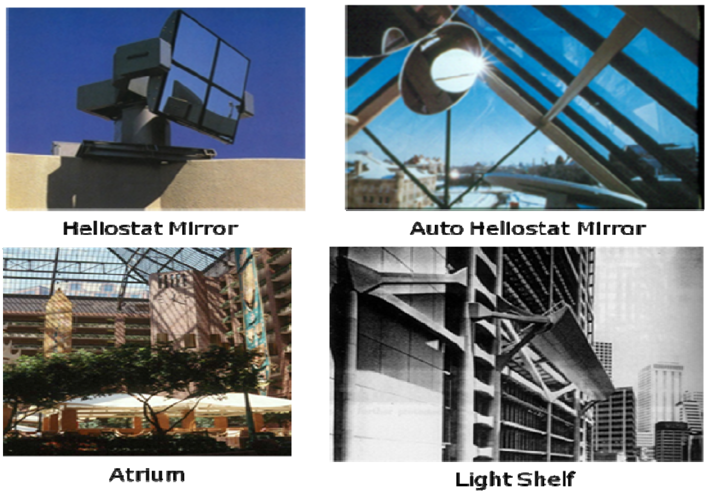


Figure 17. Passive daylighting System (CTBUH, 2008c)

4.2 *Case Studies of sustainable super tall building)*

As seen in Table 6, CTBUH rewards super tall buildings that achieve sustainability for high-rises and improved quality of urban environment. The reward is for construction that already has proved sustainability result and the assessment criteria are as follows.

Table 6. CTBUH sustainability assessment criteria

The environment	Adequate use of land, innovative use of construction materials, energy conservation, alternative energy use, minimizing the impact on the environment through reduction in water resource consumption and air pollution.
humans	positive impact on residents and their living quality
community	proved correlation between the present and future need of the community
economy	buildings boosting economic vitality for tenants, owners and community

1) Hearst Tower (USA)

New York's Hearst Tower was rewarded as the best sustainable super tall building of 2007 by the above 5 standards. (see Fig.18) The tower was constructed in 2006 and has 42-story (182m) housing corporate headquarter, commerce facility and other business. Awarded Gold Leed Certification by US Green Building Council, the tower provides panoramic view on Central Park and has effective diagrid design for heating, saving energy by 26% compared to other buildings. Thanks to this unique design, 2000 ton worth of steel is saved and 90% of used steel is recycled one. There is a tank storing 14,000 gallon of rainwater on the top of the building and that rain water is used in artificial waterfall and cooling system that grow water plants and manage the temperature and humidity of the lounge. This system reduces the amount of sewage by 25%. Aside from that, the tower uses variable air volume system, central air control system on the 18th floor, temperature control system on each floor, floor materials of radiant heating system for lounge heating, 100% external air cleaning cycle for auto-control, indoor air control system, sunlight sensing device, humidity sensing and controlling device, low-pollution materials, CO2 sensors and VOC.

Fig. 18. Hearst Tower(USA)

2) The EDITT Tower(Singapore)

A major idea of this 26-story building is vertical urbanization, which embodies the streets in vertical space. It has vertical landscaping and sky lounge with eco-friendly approach and tower design. There is a system accumulating and recycling rainwater on the top. As Expo tower, the high floors are for businesses and lower floors are for stores, exhibits and conference rooms, changing into offices or apartment later.

One of the issues of super tall buildings is a weak space connection. In order to address this issue, in huge pedestrian space for walks and shopping, there are cafes, performance stage and observation deck. By connection landscaping lamp with indigenous plants up to the 6th floor, public space is expanded vertically, highlighting space flow. This landscaping lamp is effective in conserving energy for cooling.(see Fig. 19)

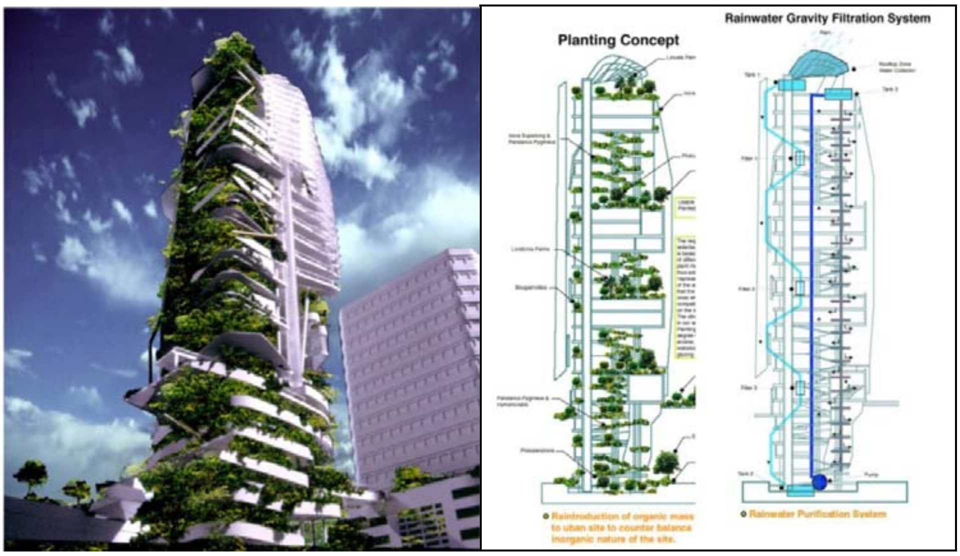


Fig. 19. The EDITT Tower(Singapore)

3) Chong Qing Tower(China)

Chong Qing Tower is designed for a company headquarter located in China's Chong Qing region(see Fig. 20). Spiral lamps stretching from the basement to the top of the building provide natural ventilation function, lots of plants, sunlight and rainwater for the building. It has also a facility collecting rainwater and sunlight and photoelectric cell panels.

Fig. 20. Chong Qing Tower(China)

4) Eco Bay Complex(UAE)

Eco Bay Complex(see Fig.21) using the concept of eco-friendly green oasis serves as a series of parks and public network established in five buildings, connecting giant plaza on the ground to the top. Usually, comple++xes in this region have high access to the streets or are closed facilities that completely control the temperature and the climate. On the contrary, this complex combines two different types and is designed as shady pedestrian space of half-closed and natural cooling effects. Thanks to this traits, natural cooling, ventilation, humidification and shading for energy consumption is possible. The first purpose of this design is energy consumption through life cycle but visual symbol is also important.

Fig. 21 Eco Bay Complex(UAE)

5) Dynamic architecture(UAE)

Horizontal windmill of Dubai's dynamic architecture generates 0.3megawatt of power and a total of 48 windmills are installed at the bottom of the building(see Fig.22). One windmill generates power that can be used for 50 households. As there are 200 households in this building, power generation from the other 44 windmills will go to neighboring buildings.

Italian architect, David Fisher, who designed this moving building, asks people to aggressively find out a new way rather than dwell on the present, saying "Right things are good, but good things are not always right."

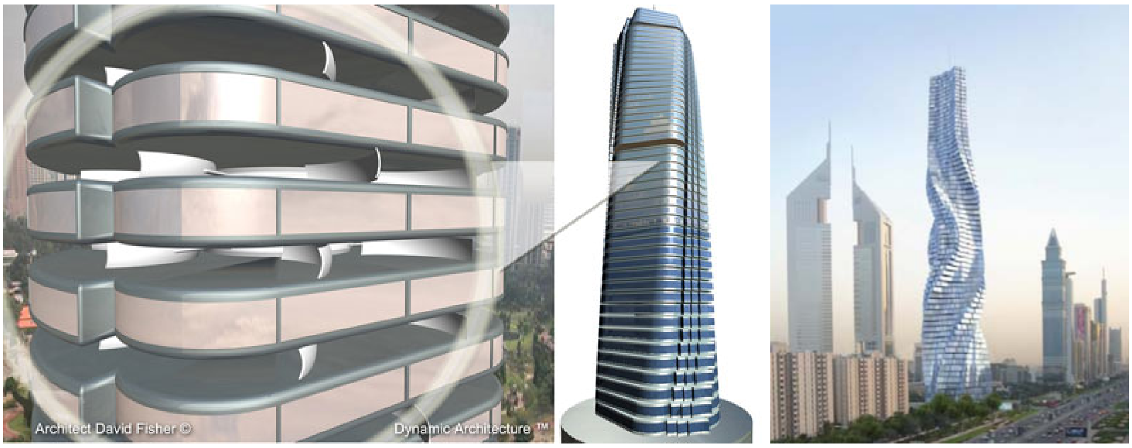


Fig. 22. Dynamic architecture (UAE)

6) Marina Bay Sands Hotel(Singapore)

Marina Bay Sands Hotel(Singapore) will be completely constructed in December 2009 with three stories below and fifty-seven above the ground. In particular, three buildings with a slope of 52 degrees converges on the 23th floor(70m). On the upper part of the building worth 200m height, three buildings are connected, creating Sky Park of 12,000 m^2 and increasing the hotel’s connection.

Fig. 23. Marina Bay Sands Hotel(Singapore)

7) Seoul LITE (Seoul, Korea)

The building will be the world's tallest business tower complete with complex functions of a futuristic city, including office/residential spaces with pleasant environment, top-notch shopping malls, world-class cultural and exhibition facilities. The outward appearance of the building will be made in a style reminiscent of the windows of traditional Korean houses. Its design specifies the installation of an exterior super skin containing 40,000 LED panels that emits light of various colors as shown Fig. 24(a).

The ’interface void’ (or bamboo-type) structure of the building will enable natural ventilation and wind power generation by utilizing the difference in air pressure between the ground level and the highest floor as shown Fig. 24(b).

A mirror installed in the building will direct sunlight towards the lower floors as shown Fig. 24(c). That, along with the use of geothermal heat and a photovoltaic generation system, using the side walls of the building, will make it possible to save considerable energy.

The greening of the rooftop of the lower sections of the building will bring about a heat insulation effect. The installation of automatic ventilation windows on the surface of the building will aid the supply of fresh air and save considerable energy.

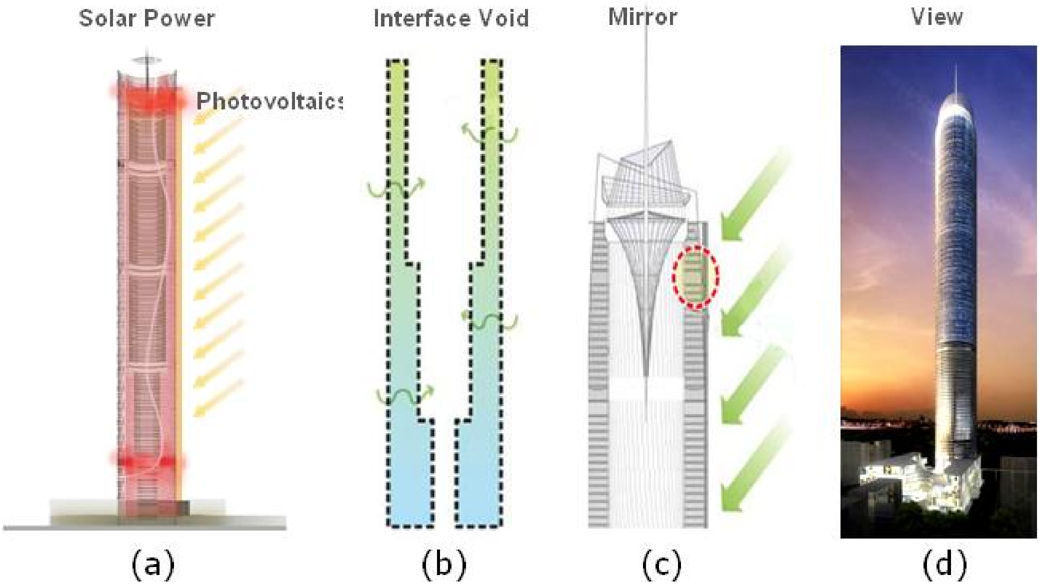


Fig. 24. Seoul LITE (Korea)

Buildings above connect the ground to the top vertically through horizontal distance of buildings with public square inside. This design integrates various environmental needs of society and cities, becoming visual symbol for sustainable life. This system, labeled a network of vertical gardens, satisfies two different needs at the same time: The first is for natural ventilation, cooling and humidification and finally air purification. The second need is for leisure and space for interaction.

5 CONCLUSIONS

As for construction, the economy and society have an inseparable connection. For instance, the World War 2 created concrete box-type buildings for the purpose of post-war recovery. The first oil shock made glass atrium for natural light in fashion around the world. Now, super tall buildings that are meaningful as strategic goods for improving urban competitiveness has emerged as a new driving force for construction industry and at the same time have faced the challenge of economic and environmental sustainability. Accordingly, a way to maintain ESSD, preserving the environment is highlighted.

This paper looks through needs and examples of sustainable super tall buildings in compact city. On the conclusion, in recent super tall buildings, rather than the height and total stories, space openness, functions and design become more important. In addition, environmental-friendliness is vital more than ever and super tall buildings play a important role in creating energy-conservative urban structure in compact city.

Modernism construction of Mies van der Rohe, famous for the phrase “Form follow function” has changed into the phrase “Form follow environmental” in modern super tall buildings. In other words, as super tall buildings evolve into embracing activities and functions unexpected in the past, the use and height will increase further.

Hence, super tall building will develop further to maximize its advantage such as realizing compact city and serving as an artificial tourism attraction by overcoming high construction and maintenance costs.

REMARKS

- Tall building is not good or evil, it is a choice
- Tall buildings succeed to the urban history, culture and sprit.
- Tall buildings bring a matter to a social, economical, environmental settlement sus-

tainably.

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Solar Urban Planning to EU 20-20-20 Targets

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ABSTRACT: Portugal, notwithstanding great investments in renewable energy production, still has a great dependence of fossil-fuel based electricity.
This scenario leads to not only economic problems, as Portugal does not explore any oil or gas reserve in its territory but also ecological and sustainability issues.
The European Union has set goals, known as the “20-20-20“that require a paradigm shift of the entire energy system. Portugal, taking advantage of its geographical position, is well placed to reach these targets and become a dominant player in the European renewable energy market.
This paper aims to contribute to a mindset change regarding energy production in urban context. On this basis, a case study in the city of Beja is presented to show the potential of photovoltaic systems implementation in the urban context and discuss the finance analysis of the PV generation. Regardless of the obtained results, the research looks at Solar Urban Planning as a tool to achieve EU’s 20-20-20 goals and define the path towards Zero Energy Buildings (ZEB).

1 INTRODUCTION

Portugal is dependent on foreign oil producing nations to meet its energy needs. This fact leads to the lack of energy security and the mercy of market price trends. The dependency on fossil fuel based energy resources creates various economic and environmental problems.

In the last decades both developed and developing countries have been subjected to a rapid urbanization process, this fact has led to a significant increase of the energy consumption in the construction sector (Gonçalves, 2004). Some estimates reveal that a 1% increase in urban population leads to a 2% in energy consumption (Santamouris, 2001). Other statistical data show that cities are responsible for two thirds of world energy consumption and 70% of global greenhouse gas emissions even though they only hold about half of all human population. By 2030 it is predicted that cities will be responsible for 73% of global energy demand and 80% of greenhouse gas emissions mostly due to the transportation and construction sectors (heating and cooling) (Ramage, 1997). In the urban context, the housing sector is responsible for 30,2% of total energy consumption (Jager-Waldau, 2007). For this reasons, efforts should be pursued to change the culturally rooted energy consumption patterns. Most studies that aim to change the urban energy consumption paradigm are based on three main pillars: Endogenous Energy Resources; Save and Conserve; Efficiency. (EU European Union, 2005)

However, this change cannot disassociate itself from the potential of renewable energy. Portugal is blessed with favorable geographic conditions compared to other European countries and by implementing renewable resources, can invert its energy dependence and becomes a dominant player in terms of sustainable energy use. Regardless of these opportunities the European Union has set energy targets for 2020 that seek to increase renewable energy use to 20% of total, reduce 20% of greenhouse gas emissions (compared to emissions in 1990) and increase 20% in energy efficiency. In order to achieve these goals tackling energy use in the urban sector is fundamental (European Comission, 2012).

2 PHOTOVOLTAIC ENERGY GENERATION IN THE URBAN CONTEXT

In the European context Portugal has extraordinary potential in terms of renewable energy production, particularly solar energy since it is one the countries in Europe with the largest incidence of solar radiation throughout the year. There are two main factors when studying the potential for photovoltaic energy generation in a particular place: solar irradiation and insolation. In Portugal, these two variables, present values between 1.400kWh/m^2 and 1.700 kWh/m^2 for average annual solar irradiation and between 1.800h and 3.100h for average yearly insolation (hours). These values place it at a comparative advantage to other European countries (Projecto GREENPRO, 2004).

However, when studying the installation of a photovoltaic production system (which is heavily dependent of the aforementioned geographic variables) in the urban context there are more variables that influence it affecting the profitability of the installed modules. Among all those that require careful study, road pattern and orientation, road width, building height, building type, existence of overhangs or balconies deserve to be mentioned with greater emphasis.

2.1 *Road orientation*

Figure 1 shows as the road pattern affects buildings orientation and consequently their solar energy production potential. It is important to note that in Portugal the optimal building orientation is south. The conclusion is that east-west aligned roads generate south facing facades that have better energy performances (Projecto GREENPRO, 2004).

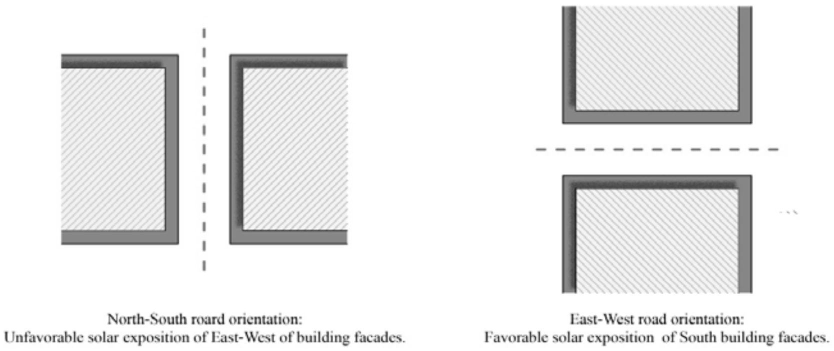


Figure 1. Road orientation (Amado M., 2005)

2.2 *Road width and building height*

These factors are related to urban density and patterns and have a direct influence on the amount of sunlight that a building receives. The careful study of these parameters is therefore required to ensure that photovoltaic systems are installed in the best suitable surface (facade or roof). The amount of shading can be calculated using the expression:

$$Ho = arctg \frac{H}{d} \tag{1}$$

"Ho" is the obstruction angle; "H" is the facing building height "d" is the distance between buildings.

2.3 *Building type*

Building type and its components, whether at the facade level or rooftop level, is a critical factor that should not be overlooked. This factor will determine the way in which photovoltaic systems are implanted regarding available areas, noteworthy architectonic elements (chimneys, antennas, etc.) (Figure 2).

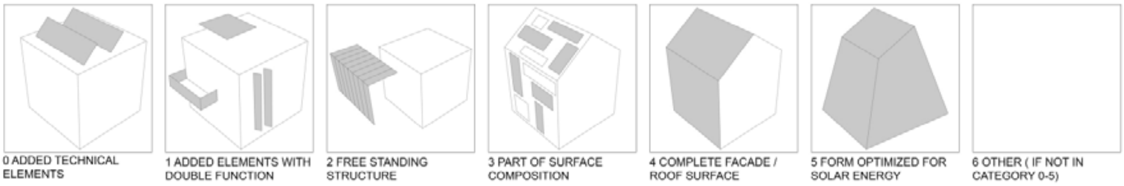


Figure 2. Building types – conceptual PV integration (IEA SHC Task41, 2012)

When rooftops are flat it is necessary to guarantee the favorable orientation of the photovoltaic systems taking into account the latitude and the shading among PV panels arrays. The correct distance "L" can be calculated depending on their height "C" (or any other obstructing element) and the latitude values (Benito, 2010):

$$L = 1.5 \times C \text{ for Latitudes between } 25°\text{-}35° \quad (2)$$

$$L = 2 \times C \text{ for Latitudes between } 35°\text{-}45° \quad (3)$$

When the morphological urban pattern is not the most efficient towards the production of solar power new strategies should be developed to guarantee the conditions for good solar panel efficiency. One of these strategies may be the setting aside of single urban blocks for energy production using various buildings integrated in a power generating system (Figure 3).

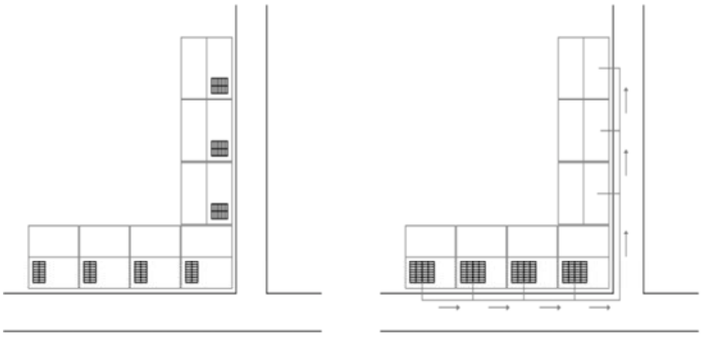


Figure 3. Aggregate block model for energy production (Rodrigues, 2012)

In Figure 4 two distinct options for energy generation are presented: the first option is the most conventional and regardless of road and building orientation, individual modules are installed for each home; the second option is an integrated and aggregate block model where the photovoltaic models are over dimensioned in the buildings where orientation is most favorable (south) so that the excess production in these buildings can be used in other buildings with lower energy generation potential.

3 METHODOLOGY

The methodology used (Figure 5) for the development of this research was based on a state of the art analysis that focuses on the different potential of renewable energies and examines successful cases study. The methodology is composed by four different phases: the first is the study of the selected block in four different dimensions: demographic, urban, climatic and geographic. In the second phase, the results obtained in the first step are re-examined to achieve a greater and more rigorous understating of the real context. In the third phase the total amount of photovoltaic energy that can be produced is quantified applying the previously studied parameters and compared among the various available energy-producing systems. The fourth phase consists in an economic analysis of investment versus return.

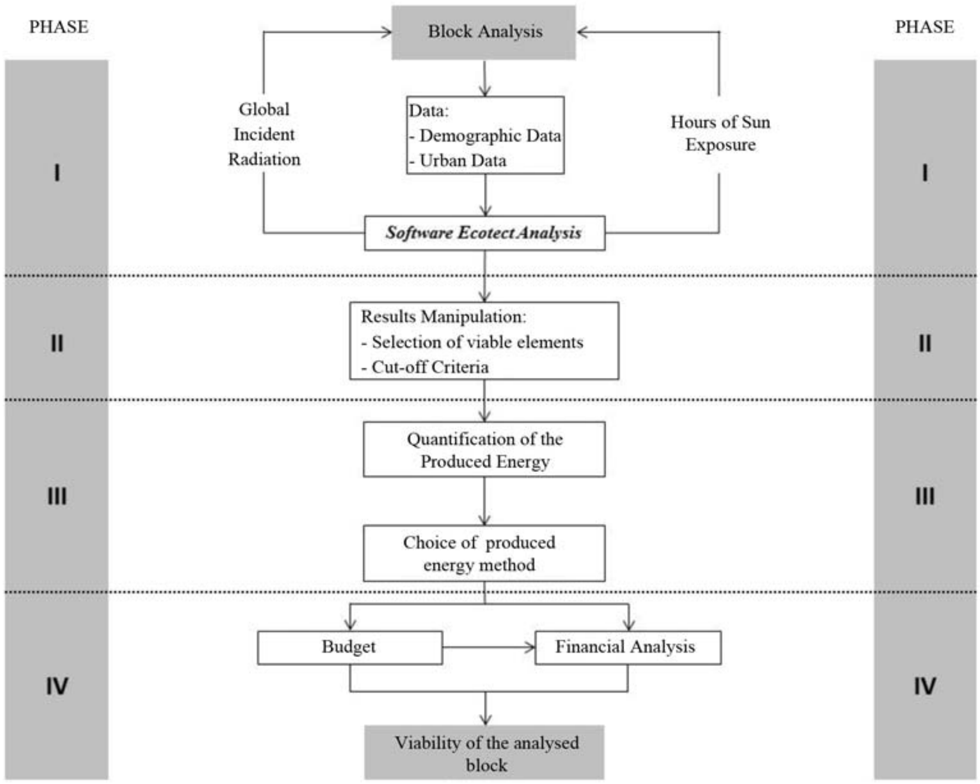


Figure 4. Methodology (adapt from Amado, 2005)

4 CASE STUDY

The caste study developed aims to calculate through an investment and cost/benefit analysis the solar energy potential of a given urban block in various different morphological and climatic conditions.

4.1 *Phase I: Case study description: demographic and urban data*

The case study is located in the city of Beja (Portugal) and its physical parameters are described in Table 1. The block is composed by 10 buildings that are homogenous in their height (15 meters) and their number of floors (4). All buildings are destined for housing (Table 2). To effectively manage the study the buildings are numerated 1-10 Figure 6.

Table 1. Space distribution in the case study block

Total block area	7665 m^2	-
Total building area	2992 m^2	39%
Roads and parking	2452 m^2	32%
Public space	2221 m^2	29%

Table 2. Number of apartament (apart) units and inhabitants (hab) per unit

Building	1	2	3	4	5	6	7	8	9	10
Apart.	12	8	10	11	8	8	8	12	12	8
Hab.	34	20	26	30	24	24	30	34	34	32

4.2 *Phase I: Case study description: climatic data*

To analyze in a dynamic and integrated way all the urban and climatic features, the software *Ecotect Analysis* was used. By modeling each building individually the software returned data for incident solar radiation, insolation, areas and volume of each building. (Figures 7; 8).

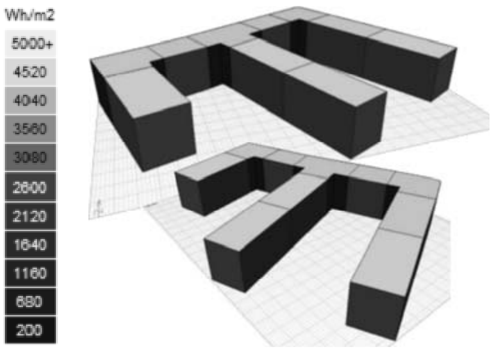


Figure 5. Global radiation (Rodrigues, 2012)

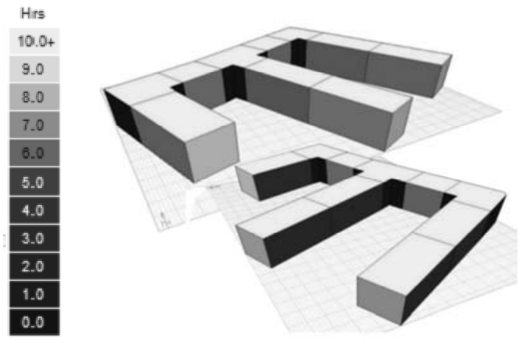


Figure 6. Daily mean insolation (Rodrigues, 2012)

4.3 *Phase II: Viable analysis*

This phase begins with the analysis of the various elements that may be considered efficient in a solar producing perspective. It was concluded that all flat roofs are viable and that only some pitched roof and facades are viable. Each façade, which did not have a minimum insolation value of 5 hours and 30 minutes, has to be discarded (Benito, 2010). Once all the elements have been characterized and evaluated, they are introduced in Ecotect to quantify the amount of net area of those which don't include architectural elements (windows, etc.). A set of criterions was introduced to estimate the total available area in all buildings facades and roofs.

4.4 *Phase II: Results: Reduction criteria applied to building roofs*

The first criterion is related to the different typologies of roofs. Comparing Figures 7 and 8 with Figure 6, the flat design of the rooftops is obvious. For this reason a reduction criteria was applied and depending by the typology of the roof (Figure 9), only those which are rightly orientated in SE-SW are considered.

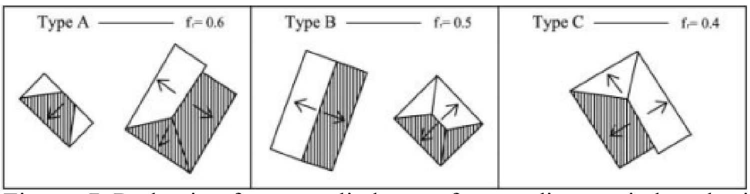


Figure 7. Reduction factor applied to roofs according to pitch and orientation (Amado & Poggi, 2012)

In Figure 7 it is possible to observe that the Type B factor is the most adequate to the case-study block and it corresponds to the value fr = 0.5. For buildings 2 and 4 the Type A factor (fr = 0.6) was applied since 50% of its surface can be used.

The second criterion applied is related to estimate the net areas without the obstruction of protruding elements in the roofs. This criterion is applied following the Facility Coefficient (Cf) according to Izquierdo's work (Izquierdo, Rodrigues, & Fueyo, 2008). This criterion takes in to account population density (D_p) and building density (D_b). Since the city of Beja has a population density lower than 2400 hab/Km² and a building density lower than 1000 homes/Km² then D_p - D_b corresponds to L-L (*low - low*) meaning that the facility coefficient is Cf = 0,92. In this way an approximation of the available net areas to install solar photovoltaic modules can be calculated.

4.5 *Phase II: Reduction criteria applied in building façades*

After excluding all facade areas that are not viable due to weak solar exposure, the first criterion applied is the removal of the lowest floor because of equipment safety reasons and pedestrian comfort. This criterion is demonstrated in Figure 8.

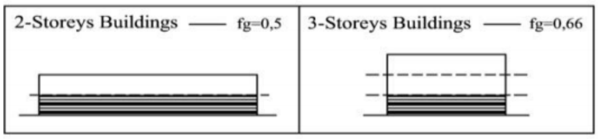


Figure 8. Ground floor reduction factor (Amado & Poggi, 2012).

As the case study is composed by 4 stores buildings, the factor to apply for the façade reduction is fg = 0,75. In the integration of photovoltaic systems in facades, windows and other elements aren't a negligible factor. To correctly assess the available facade area, a percentage ratio of (R_v) 20% was introduced, representing glass spans up to a minimum of 10% which is what is established by the General Regulation on Urban Buildings (Amado & Poggi, 2012) (Ministério das Obras Públicas, 1951).

Another criterion to estimate available façade areas is related to the building's age. Older buildings, such as those studied, have not been designed for solar panel installation so a factor of 10% is used to take that fact into account.

By the use of the described reduction factors, the close-to-reality net area available to install solar energy production systems can be calculated for each building in the block.

4.6 *Phase III: Quantifying produced energy*

Once all the required factors to determine potential energy production in each building have been gathered, the following expression was used (Benito, 2010):

Annual photovoltaic energy production= $PR\times\eta\times(E_G\times A\times 365)[kWh/m^2/year]$ (4)

A system energy loss ratio of 25% (PR = 0,75) was considered (Nordmann, 2007). Global incident radiation was calculated using *Ecotect.* The yield (η) of each photovoltaic module was extracted from manufacturers tables (Table 3).

Table 3. Photovoltaic panels

Module	Martifer Solar PV modules 210p
Dimensions	1639 x 982 [mm]
Maximum power	210 Wp
Module yield (η)	13,1%

By using the formula (4) and data of table 3 it is possible to calculate the total amount of energy produced by each building in the case study (Table 4).

Table 4. Total energy produced by panels

Building	Place	Area [m2]	Mean daily Global Radiation [Wh/m2]	Area x Radiation [Wh]	Energy Production (PV=PRxηx(EgxAx364)/1000) [KWh/ano]	Global production by Building [kWh/year]
Building 1	Roof	168,10	4413,44	741904,96	26402,54	54049,34
	Facade	155,90	2.377,32	370626,5653	27646,79	
	Facade	213,51	1.902,65	406241,5073		
Building 2	Roof	154,52	4335,87	669984,22	23843,06	32470,50
	Facade	127,42	1.902,65	242428,7639	8627,433634	
Building 3	Roof	87,54	4301,50	376573,95	13401,33	22559,58
	Facade	123,83	2.078,27	257344,6499	9158,252728	
Building 4	Roof	201,12	4301,50	865128,96	30787,78	30787,78
Building 5	Roof	88,67	4301,50	381401,95	13573,14	22356,91
	Facade	120,96	2.040,47	246821,6204	8783,764416	
Building 6	Roof	125,47	4301,50	539716,75	19207,17	19207,17
Building 7	Roof	156,78	4335,87	679791,17	24192,07	37996,14
	Facade	214,03	1.812,30	387891,0566	13804,07298	
Building 8	Roof	154,40	4413,44	681423,86	24250,17	46943,50
	Facade	210,60	1.888,18	397651,3064	22693,32687	
	Facade	104,57	2.295,43	240025,5988		
Building 9	Roof	151,61	4413,44	669127,06	23812,56	37553,13
	Facade	213,06	1.812,18	386106,7808	13740,57506	
Building 10	Roof	147,31	4413,44	650157,06	23137,46	45940,82
	Facade	210,60	1.946,43	409923,622	22803,35679	
	Facade	99,42	2.321,81	230845,0972		

4.7 *Phase III: Energy production type*

To choose between the various possibilities to produce energy it is necessary to compare the available energy production of each building with their needs. The *per capita* energy consumption according to INE is 1359 kWh/hab/year (INE Instituto Nacional de Estatística/DGEG Direcção Geral de Energia e Geologia, 2010) so it is possible to estimate the needs for each building and then select the type of energy production that can bring the best results.

4.8 *Phase III: Energy type choice: Individual energy production*

By considering the individual energy production in which all the produced energy is consumed in the building where the system is installed it is possible to determine the energy balance for each building (Table 5).

Analyzing Table 5, only 40% of the buildings can achieve a positive balance leading to not consider viable this type of energy production system.

Table 5. Building energy balance

Building	Annual energy needs [kWh/year]	Annual energy production [kWh/year]	Energy balance (production – needs) [kWh/year]
Building1	46206	54049,34	7843,34
Building2	27180	32470,5	5290,5
Building3	35334	22559,58	-12774,42
Building4	40770	30787,78	-9982,22
Building5	32616	22356,91	-10259,09
Building6	32616	19207,17	-13408,83
Building7	40770	37996,14	-2773,86
Building8	46206	46943,5	737,5
Building9	46206	37553,13	-8652,87
Building10	43488	45940,82	2452,82

4.9 *Phase III: Energy production type, integrating all buildings in an internal grid system*

By integrating all buildings in an internal grid system, the excess of energy production in Buildings 1 and 2 can be used to bridge the needs of building 3 and by using the energy excess of buildings 8 and 10 the needs of building 7 may be met (Figure 11). Although this type of distribution met 60% of the blocks energy needs, 40% of buildings still have a negative energy balance which doesn't meet the goals set out for this work.

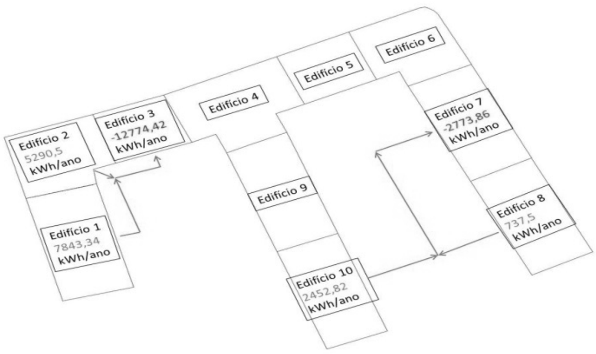


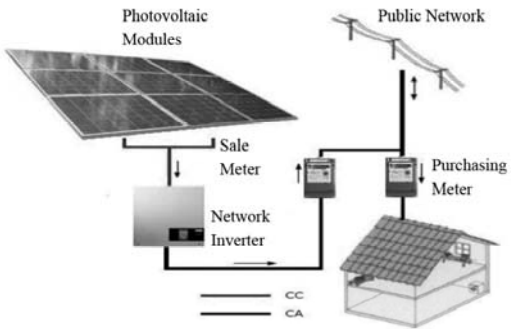
Figure 9. Internal grid system of energy distribution (Rodrigues, 2012)

4.10 *Phase III: Energy production type: microgeneration*

Facing the obtained results with the above described types of energy production, the microgeneration system appears as a plausible solution where produced energy could be sold to the electric grid without being consumed directly in the buildings or inside the block as in the internal distribution system. The buildings will then sell and buy energy to and from the public grid.

4.11 *Phase IV: Feasibility study: budget*

Once the type of energy production was chosen, the necessary components for its operation have been determined and the total amount of the investment for each building calculated. The components of a microgeneration system are shown in Figure 12:



- Photovoltaic modules;
- Support structure;
- Inverter:
- Selling meter;
- Basic cables and installation equipment.

Figure 10. Proposed microgeneration system (Rodrigues, 2012)

Knowing available areas for system installation and their dimensions, the number of arrays for each surface type and building, can be assessed. With the number of systems calculated, the total amount of generated power can be known and used to correctly dimension the inverter and know the total amount of the investment (Table 6).

Table 6. Investment by building

Building	Investment (no VAT)	Investment (with VAT)
Building 1	104.987,04 €	129.134,06 €
Building 2	58.035,84 €	71.384,08 €
Building 3	45.618,72 €	56.111,03 €
Building 4	41.651,52 €	51.231,37 €
Building 5	45.354,24 €	55.785,72 €
Building 6	28.248,96 €	34.746,22 €
Building 7	75.525,6 €	92.896,49 €
Building 8	74.467,68 €	91.595,25 €
Building 9	74.996,64 €	92.245,87 €
Building 10	93.614,4 €	115.145,71 €

4.12 *Phase IV: Block feasibility: financial analysis*

To reinforce the validity of this work a financial analysis was carried out in which the total amount of produced energy by the photovoltaic system was used to calculate return-on-investment versus current energy tariffs. The selling tariff (proposed by the utility Energia de Portugal, EDP) is from 2012 onwards.

Table 7. EDP Selling tariff (to public grid)

Period	Selling tariff
First 8 years	0,326 €/kWh
7 following year	0,185 €/kWh
16^{th} year onwards	Selling price equals buying price

Regarding the selling tariff each apartment will have an independent meter and will continue to purchase electricity independently. The contract power by apartment is 6,9 kVA and for the buildings common areas the contracted power is 3.45 kVA. Each client is therefore subject to the low voltage tariff (up to 20,7 kVA) of 0.139 €/kWh. Considering the units lifespan of 25 years, a 0,8% decrease in efficiency in energy production per year and an annual inflation of 3% the financial analysis for each building was calculated in Table 8 with unit maintenance considered.

Table 8. Return-op-investment study

Building	Return-on-investment 25 years	*Payback* [years]
Building 1	186.811 €	7,5
Building 2	118.422 €	6,9
Building 3	75.761 €	7,8
Building 4	128.739 €	5,2
Building 5	74.901 €	7,9
Building 6	77.529 €	5,7
Building 7	129.209 €	7,7
Building 8	182.813 €	6,1
Building 9	127.270 €	7,7
Building 10	153.400 €	7,9

To better assess the validity of this work a cost-benefit analysis was made for each building and presented in Table 9.

Table 9. Cost-benefit analysis by building

Building	Initial Investment	Return-on-investment 25 years	Annual energy production [kWh/year]
Building 1	129.134,06 €	186.811 €	54049,34
Building 2	71.384,08 €	118.422 €	32470,5
Building 3	56.111,03 €	75.761 €	22559,58
Building 4	51.231,37 €	128.739 €	30787,78
Building 5	55.785,72 €	74.901 €	22356,91
Building 6	34.746,22 €	77.529 €	19207,17
Building 7	92.896,49 €	129.209 €	37996,14
Building 8	91.595,25 €	182.813 €	46943,5
Building 9	92.245,87 €	127.270 €	37553,13
Building 10	115.145,71 €	153.400 €	45940,82

The results show that the adopted solution (microgeneration system) offers a positive return in all buildings. However if the analysis is made by apartment (Table 10) against the current energy bill not all apartments show a positive return (Table 11). This means that the investment does not produce positive returns after 25 years (unit lifespan) in all buildings.

Table 10. Cost-benefit analysis by apartment by building

Building	Investment by apartment	Return-on-investment by apartment
Building 1	10.761,17 €	15.568 €
Building 2	8.923,01 €	14.803 €
Building 3	5.611,10 €	7.576 €
Building 4	4.657,40 €	11.704 €
Building 5	6.973,22 €	9.363 €
Building 6	4.343,28 €	9.691 €
Building 7	11.612,06 €	16.151 €
Building 8	7.632,94 €	15.234 €
Building 9	7.687,16 €	10.606 €
Building 10	14.393,21 €	19.175 €

Table 11. 25 Year energy bill liquidation by apartment

Buildings	Return-on-investment by apartment (25 years)	Energy bill by apartment (25 years)	Liquidated percentage of energy bill (25 years)
Building1	15568 €	13380,48 €	116,35 %
Building2	14803 €	11806,31 €	125,38 %
Building3	7576 €	12278,56 €	61,7%
Building4	11704 €	12879,61 €	90,87%
Building5	9363 €	14167,57 €	66,08%
Building6	9691 €	14167,57 €	68,40%
Building7	16151 €	17709,46 €	91,2%
Building8	15234 €	13380,48 €	113,85 %
Building9	10606 €	13380,48 €	79,26%
Building10	19175 €	18890,1 €	101,5%

The results show that only 40% of buildings (1,2,8,10) have a totally liquidated energy bill after 25 years and generate some extra returns.

5 CONCLUSIONS

Based on the presented outcomes it is evident that the influence of an urban planning process that orients the buildings to take the most advantage of solar energy production potential is extremely important. The buildings with the biggest south and south-west facing areas (Figure 13) have the best possibility to generate positive returns.
However it is always possible to obtain economic viability in any buildings whether in existing urban contexts or new development areas. The photovoltaic systems connected to the grid should consider the aggregation of buildings to increase efficiency and reduce the need of fossil-fuel based energy. These types of systems are not only attractive in a financial point of view but also in a sustainable development perspective by reducing the need for fossil fuels it has a positive impact on the environment.

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Power of a Million Small

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ABSTRACT: This paper is not about a special efficient passive house or another type of sustainable house, but rather it deals with the power of a million buildings together and their daily related and transferred energy.
Recent debates discuss how a house can be as sustainable and energy-independent as possible. However, it is important to remember that the bodies are much more efficient sticking together with simple shapes and sizes.
Peeking where E. F. Schumacher left us with “Small is beautiful”, it is important to know how the modern economy perceives rich and poor countries, their development and how we understand the right size and population of a great city, or convenient efficiency of big and small organizations. These concepts, already in use by urban planners in their definition of sustainable cities, are important to study the stability between the necessary quality of city life and the appropriate power to use.

1 INTRODUCTION - THE PROLOGUE

Which type of society can generate more power, efficiently and effectively?

Imagine our universe as a great ball of energy, made up of different kinds of strengths, in different directions achieving, in the end, a perfect balance. We shall not force it; we shall embrace it as a gift. Everything seems to point towards the biggest metropolitan cities as great powers, such as economy or energy. Is this true, in fact?

Tokyo, New York or Lagos, have different networks and qualities, but what they have in common, is the fact that they are great economic powers and the world’s most populated cities. Next there are medium and small cities from 10.000 to 500.000 citizens, skipping all other small villages from a dozen families to others much bigger.

All urban areas from city to villages all generate power and they all connect somehow with each other. All these different kinds of strength pull their own energy in different directions and they produce, conserve and transfer energy and matter everyday.

It is becoming more and more important to understand that citizens should have a proper quality of life, while taking into consideration all the difficulties certain countries are having, specially the most developed ones. Efficiency programs are certainly important to reduce unnecessary losses, and in the mean time effective programs are certainly of key importance to achieve better and faster certain means, and not only incomes and the human factor. There is always something missing in the middle that is sought out and depends on the variables to be used and the all universal interaction. This is a question that must be answered in the paper, which leads to the possibility of using million of cities instead of a single major one.

There are two main issues in this paper, one is energy and other is urban planning. In order to present a different perspective on what has been being discussed, like efficient energy in buildings, and having an urban planning approach, there will always be two different perceptions between specific energy and a general city. Finally, all these sciences were made for mankind and its environment, therefore it is necessary to understand this paper like Schumacher wrote his "Small is Beautiful", forty years ago, always as if people mattered!

2 THE OBVIOUS CHAPTER – THE PATH TO A NEW CITY SHAPE

We have discussions among efficient energy in buildings and creating strong regulations, but would it not be much easier if we just re-thought the city shape?

Certainly, good building isolation should be as important to a city as a whole, as the area of shapes for reducing energy transfers. Figure 1 and Table 1 demonstrate how buildings using exactly same construction methods and materials can have dramatic differences in performance with different building shapes.

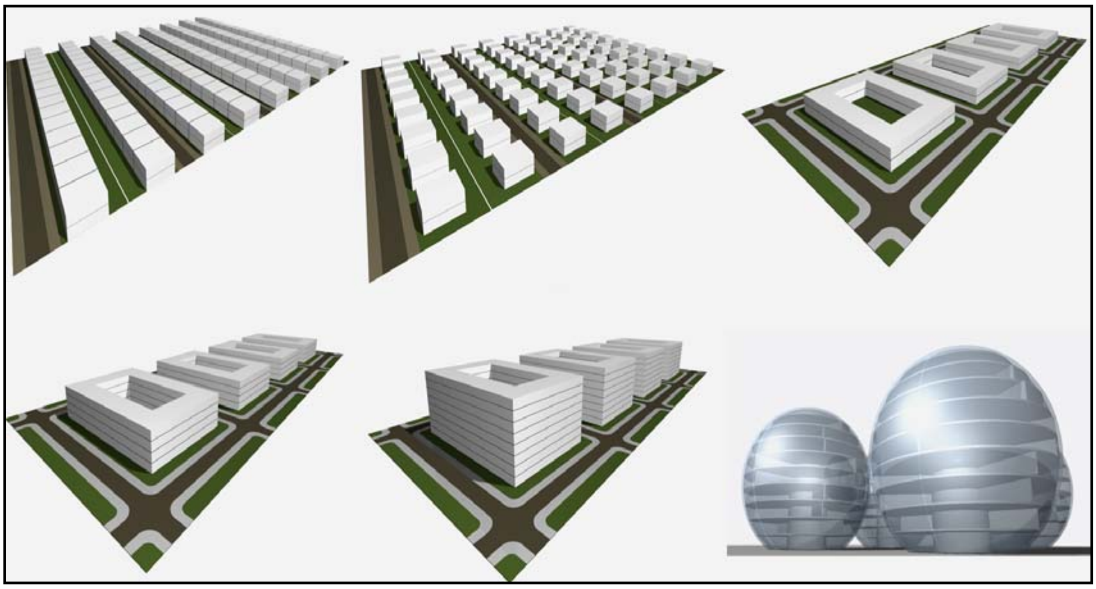

Figure 1. Simulation of 6 different possible models of city blocks in order to calculate the results of table 1.

Table 1. Different types of buildings and their thermal energy performance, with the same location (Lisbon) and same structures or materials (using a simulation according to Portuguese SCE-RCCTE Decreto-lei 80/2006 and Kwh = 0,15€)

Type of building	Annual thermal performance estimation		Monthly thermal performance estimation	Difference of losses to Independent houses or villas
	Kwh/year	Euros/year	Euros	Percentage - %
Independent house/ Villa	>8.000	>1.200	>100	0
Townhouse/ twin house	7750	1.162,5	97	3
Building - 2 stores	6864	1.030	86	14
Building – 4 stores	6317	947,5	79	21
Building – 8 stores	6044	907	75,6	24,4
Sphere – 8 stores	<6.000	<900	<75	>25

This is still very obvious as is very dense cities and building shape, which will compromise a citizen's quality of life. There are many examples of this, one is form one of the largest cities, Tokyo, in which the space, comfort can be very precisely measured with 6000 people/km², or Amadora in Portugal, a medium sized city with 7.368 people/km², lacking in some quality. Then there are other extremes like Delhi in India with 30.000 people/km² or even Manila with more then 43000 people/km². It is very clear that over density can bring bigger problems therefore, and obviously, it is not all about reducing area shapes.

So, we know that quality of life must exist in the energy conservation measures, as much inside a house, as in a city, therefore we really have to think about something more when we discuss the balance between effectiveness and efficiency. Since this balance is far from the obvious scene, our research question is:

Which type of society can generate more power, efficiently and effectively?

To advance with an answer, there needs to be a definition of: what is this power in a city?

"Power is everything" (Howard, 1995). This special sentence from the Apollo 13 movie describes one of the most important events of conserving energy. In order to keep everyone alive during the re-entry, they had to shut down almost everything so that the batteries from the LEM would not run out.

Academically speaking, it is necessary to start by defining energy as a more embracing term. Therefore, there was an intention to use the term "power" in order to avoid direct denotation to the energy term, so that there is no confusion when talking about manpower, or any other form of energy transfer. As such, it is also important to understand how this power can be such an influence in a society. Basic physics is a starting point to explain universal models as in the figure 2: open systems, close systems and isolated systems.

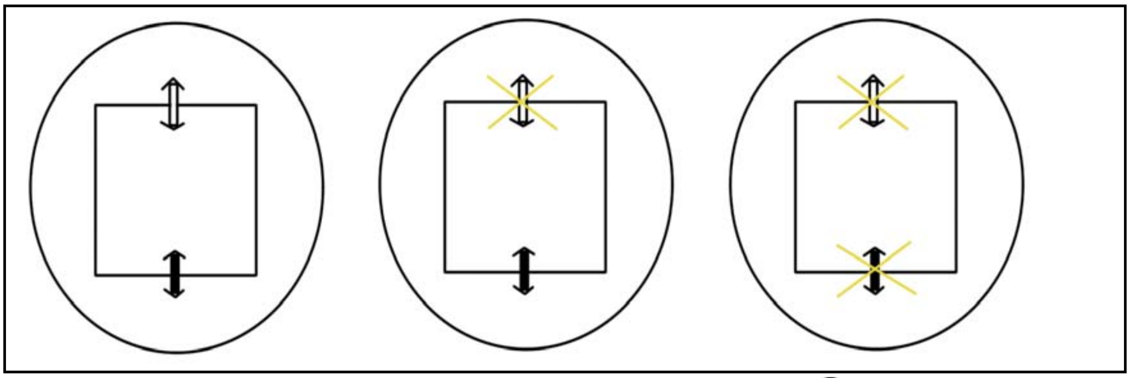

Figure 2. Basic physics explanation of different systems in the universes: ◯ = Universe; □ = Systems; (□) = Neighborhood; ⟺ Matter exchange; ⬌: Energy exchange

To understand the 3 types of possible universes, it must be understood that no city can be fully isolated; therefore, there are always energy changes. However, further analysis confirms that it is impossible to prevent matter from being transferred, particularly when there are always particles entering and leaving the systems. The city is never a close or isolated system; there are matter and energy changes. Besides this, it is essential to start to accept other attributes beside only thermal or electric as energy issues, but also include life and water. Power is used as a bigger word in this paper. It would be a good step forward for society if great programs like EPBD program accepted water as part of regulations, which allow for buildings to create better performance on bioclimatic events, like cisterns to provide public gardens or even the house itself, as well as solar panels. It would also be a greater step if urban planning were to be integrated into these programs, so that the whole performance of buildings in the neighbourhood would comply with minimum needs. Instead, the discussion continues on great performance for independent houses, like villas or single apartments. This is very specific; it is an example to add another point of view when discussing efficient energy programs like EPBD

Urban planning has been discussing the rationalization of infrastructures in a city since forever and all planners know that horizontal cities, composed by single houses can be a big problem in city management, but also to the city environment itself: like security and social issues. In the mean time, most bioclimatic examples are single houses with expensive infrastructures in order to achieve good performances.

Consequently, new and much bigger patterns have been established within this concept of efficient energy. This is important to work and to know more about cities and their development. A city needs to generate power and it needs to be competitive to survive. If energy regulations are simply created for apartments or single houses, the whole point of view is completely lost.

In order to loose this self-centric and learn more about cities it is important to ask what is really important to a city's growth? What makes it generate that great power? And, is size (as population and density) really important?

3 THE QUESTION (S) ABOUT CITY GROWTH AND CITY POWER

In 1966, Professor Christopher Alexander made a very important contribution to urban planners when he wrote, "*A city is not a tree*", destroying the normal tendency from modern architecture in the shape of the city and its impact in society. Also, contrary to the general idea for urban economies and according to OECD territorial reviews, "(…) the relationship between population size and income is not a straightforward one." (OECD, 2006, p.50) This figure below shows city incomes by GDP/person and gives some truth to Schumacher's "Small is Beautiful" point of view. However these are still cities with great incomes and with over 2 million people, and as such are always considered as being major cities.

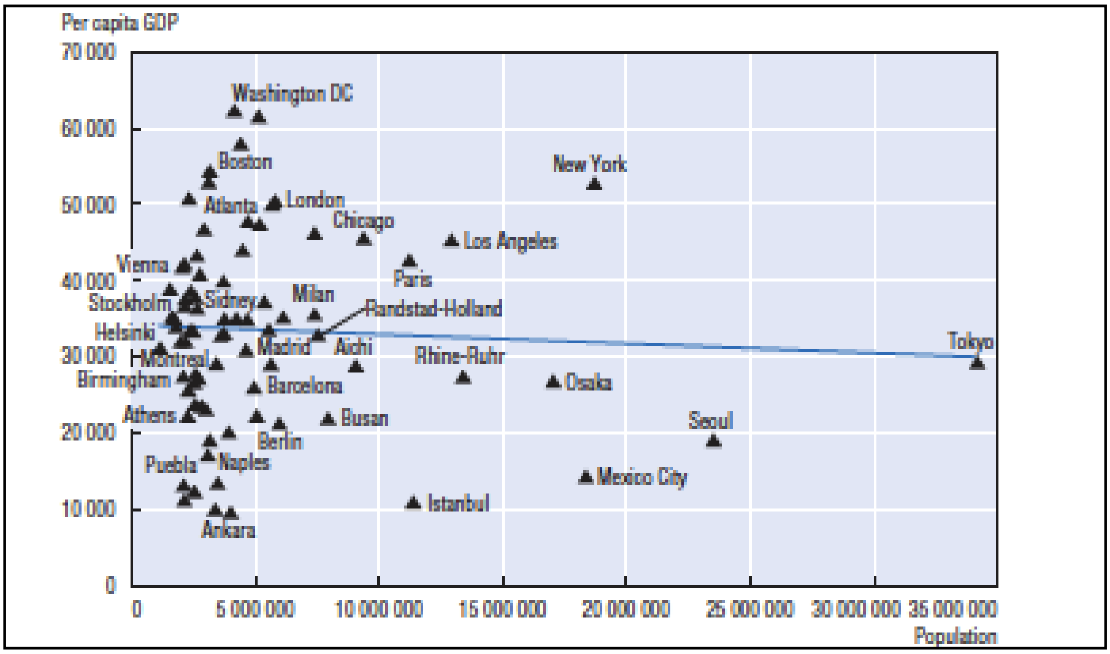

Figure 3. OECD Territorial reviews of basic competitive cities in the global economy. Correlation between population size and income in OECD metro-regions, sample of 78 OECD metro-regions (2002)

After any obvious observation of the previous chapter, there is a particular tendency to approach other views of society in order to find a strong welfare and sustainable society. Entering into sciences like sociology and economics one of the main indexes used in very important world rankings, like GDP, emerges. GDP is in fact an important index for ranking, but it can also be a detour for other purposes which are much more important like equity. OECD determined, in these territorial reviews, that city competitiveness is a broad concept; lots of factors can influence it but certainly, not city size (size as the number of population).

Looking at a specific example with Tokyo, it is possible to see that it is exactly in the middle, like the Rhine-Ruhr and the Randstad metropolitan areas (two examples to present further on). Tokyo has about 25% of the Japanese population and concentrates 33% of Japan's GDP. It does not seem to be a landmark, or even relevant to consider that the future only lies in major cities.

An examination of the Portuguese Regional GDP, Lisbon, the whole metropolitan area, has a GDP (according to 2009) of 25.800 €/person/year. Other places like Guarda District has 10.700 €/person /year, Castelo Branco has 13.700 €/person /year and Oporto's whole metropolitan area has 16.700 €/person year. On observation there is an obvious answer that says: Lisbon is the capital city, it is obvious that people earn more money in Lisbon than in other districts. But, will this answer be satisfactory? A closer look at the numbers suggests that it is acceptable to say that in Lisbon people can earn more, but it cannot be immediately accepted that people really do earn more. There is a big difference between the possibilities of achieving this to earning in reality. To dismantle this riddle another statistic is needed; the pattern between the percentages of people between wage ranks. For example, how many people (percentage) really earn more then 500€ or 1000€ or 5000€?

Un: 10^3 euros

NUTS I / NUTS II / NUTS III	Portugal					Lisboa		R. A. dos Açores	R. A. da Madeira
		Grande Porto	Pinhal Interior Sul	Beira Interior Norte	Beira Interior Sul	Total	Grande Lisboa		
1995	8.7	10.2	5.0	5.3	7.6	12.1	13.9	7.1	7.5
1996	9.3	10.7	5.4	5.6	7.8	12.8	14.6	7.5	7.9
1997	10.0	11.4	5.6	5.8	8.3	14.0	15.9	8.0	9.0
1998	10.9	12.3	6.1	6.4	9.0	15.3	17.5	8.8	10.4
1999	11.6	12.9	6.3	6.9	9.4	16.4	18.9	9.8	11.5
2000	12.4	13.3	6.5	8.7	10.5	17.4	20.2	10.3	13.9
2001	13.0	14.0	6.8	8.7	10.8	18.2	21.2	11.3	13.8
2002	13.5	14.0	7.1	8.7	11.2	19.0	22.2	12.1	16.7
2003	13.7	14.0	7.7	9.0	11.5	19.2	22.7	12.5	16.5
2004	14.2	14.4	8.1	9.1	11.8	20.0	23.7	12.8	17.7
2005	14.6	14.9	8.7	9.6	12.4	20.6	24.5	13.4	18.1
2006	15.1	15.3	9.9	10.2	13.0	21.2	25.0	14.0	20.1
2007	15.9	16.3	10.2	10.5	13.6	22.3	26.4	14.6	20.5
2008P	16.2	17.0	10.1	10.7	13.8	22.6	26.7	15.2	21.4
2009P	15.8	16.7	10.1	10.7	13.7	21.8	25.8	15.1	20.8

Figure 4. Adaptation of table D.1.5 – Gross domestic product per inhabitant by NUTS 3 (current prices: annual. Instituto Nacional de Estatítistica. Portugal 2012.

Unfortunately, it is not a common board, which seems odd for studying the citizen's equality like HDI systems. In Portugal, only regional statistics is used. However, the great metropolitan region of Lisbon has more then 50% earning less then 900€, but only 3% earning more then 2500€. In the Northern region, like the Oporto District where more then 65% earn less then 900€, and only 1,5% earn more than 2500€/year. The central region is basically the same with 900€, but only 0,6% earn more than 2500€.

A closer examination of the table shows that the discrepancy should never be as much as is seen in the GDP, there is not 40/50% more money in the common Lisbon citizen's pockets than in the rest of the common Portuguese citizen's. The money is in the 1,5% of Lisbon citizen's and certainly some of these have a lot more then 3000€.

Escalão de rendimento salarial	Portugal	Norte	Centro	Lisboa	Alentejo	Algarve	R. A. Açores	R. A. Madeira
Trabalhadores por conta de outrem	3 538.2	1 233.3	767.0	986.0	246.6	138.8	80.4	86.1
Menos de 310 euros	150.2	58.2	31.6	40.2	7.3	3.7	4.2	5.1
De 310 a menos de 600 euros	1 092.4	476.3	246.2	193.9	82.6	39.1	27.5	26.8
De 600 a menos de 900 euros	927.7	293.3	202.9	276.7	69.3	43.4	21.4	20.7
De 900 a menos de 1 200 euros	423.9	113.5	92.7	153.7	28.3	16.0	8.3	11.4
De 1 200 a menos de 1 800 euros	362.8	100.6	65.9	134.6	27.8	17.3	8.4	8.3
De 1 800 a menos de 2 500 euros	128.7	38.3	23.0	53.4	6.0	3.2	2.5	2.1
De 2 500 a menos de 3 000 euros	25.7	7.5	2.4	14.5	0.5	0.5	0.2	0.1
3 000 euros e mais euros	29.0	8.4	2.2	16.5	0.7	0.6	0.5	0.2
NS/NR	397.8	137.1	100.1	102.5	24.0	15.1	7.6	11.4

Figure 5. Adaptation of table 30. Number of population (thousands) by region/ nuts 2 – Employment statistics. Instituto Nacional de Estatítistica Portugal. 4º quarter of 2012

Unidade: Milhares de indivíduos

Escalão de rendimento salarial	Portugal	Norte	Centro	Lisboa	Alentejo	Algarve	R. A. Açores	R. A. Madeira
Menos de 310 euros	4.2	4.7	4.1	4.1	3.0	2.7	5.2	5.9
De 310 a menos de 600 euros	30.9	38.6	32.1	19.7	33.5	28.2	34.2	31.1
De 600 a menos de 900 euros	26.2	23.8	26.5	28.1	28.1	31.3	26.6	24.0
De 900 a menos de 1 200 euros	12.0	9.2	12.1	15.6	11.5	11.5	10.3	13.2
De 1 200 a menos de 1 800 euros	10.3	8.2	8.6	13.7	11.3	12.5	10.4	9.6
De 1 800 a menos de 2 500 euros	3.6	3.1	3.0	5.4	2.4	2.3	3.1	2.4
De 2 500 a menos de 3 000 euros	0.7	0.6	0.3	1.5	0.2	0.4	0.2	0.1
3 000 euros e mais euros	0.8	0.7	0.3	1.7	0.3	0.4	0.6	0.2
	11.2	11.1	13.1	10.4	9.7	10.9	9.5	13.2

Figure 6. Adaptation of table 30. Percentage of population by region/ nuts 2 – Employment Statistics. Instituto Nacional de Estatítistica Portugal. 4º quarter of 2012

Working a little bit harder on these numbers, in spite of some uncertainties or margins of error, just to see something strangely uncomfortable, it is found that in Lisbon, the 4.1% of the people is equivalent to 40.200 persons (who earn less than 310€/month). For simulation purposes If we establish the average wage into temporary fixed values, (maximum or averages wages) and calculate the difference between Lisbon's GDP and the rest of regions, the following equation is used:

$$\sum \frac{\left(\frac{Nr1}{Pr1}+\frac{Nr2}{Pr2}+\ldots\frac{Nrx}{Prx}\right)}{R} = ArGDP \qquad (1)$$

Where Nrx = average net salary by rank; Prx = population by rank; R= regions (or NUTS according to Eurostat); ArGdp = Average GDP by Region

Table 2. Description of the previous equation for Portugal and 3 main regions like North, Lisbon and Madeira. Final Row shows the percentage to the highest GDP (Lisbon region/ NUTS II)

Descriptions	Annual GDP net salary estimation in Portugal	Annual GDP net salary estimation in North	Annual GDP net salary estimation in Lisbon	Annual GDP net salary estimation in Madeira
NUTS II Max GDP	44.989.028.000 €	14.516.908.000 €	14.665.728.000 €	997.654.000€
NUT II population (active)	3.538.200	1.233.200	986.000	86.100
Average net GDP	12.715 €	11.770 €	14.873 €	11.587 €
Difference to the highest	17%	26,4%	0%	28,4%

Basically, it would be the same as the normal GDP's table, but surprisingly it is not. Most surprisingly are the percentage differences for Madeira. Only 200 people earn more then 3000 €/month. In order for this to be true, these 200 people would actually have to earn an average of 30.000 €/month (10 times more) so that Madeira could match its regional GDP. This means that equality in Madeira is very unfair when compared to the rest of the country. This also means that the 16500 people who earned more then 3000€ a month probably earn much more then 3000€. Additionally, the 200 people in Madeira, the majority of whom certainly must earn much more then 3000€ a month to re-balance the normal GDP, which is very high (second highest in Portugal)

It is essential to this paper is to prove that a great city is not necessarily so great or powerful, even for economical growth and, certainly, according to a better life, when compared to the rest of the medium size and small cities as happens in Portugal.

Basically, the purpose of this chapter is to understand that a city model is irrelevant to it is size but very relevant to all the directives within, for certain conserving or expending more energy as well as the organization of all infrastructures and everything which provides good self-esteem.

It is also important to understand that the tendency for equity in a simple salary is the same as equity for benefits. There is a phenomenon where it is very common to populations living in big cities enjoying good quality of life and paying less for certain pleasures, such as thermal comfort, than those populations facing major economic difficulties and for whom these benefits are impossible.

Finally, it can be said that size does not matter but a well dimensioned size with the correct measurements does. These measurements mean the purposes in which all networks are achievable. In the case of energy it is understood that conserving energy is a real necessity in order to avoid transfers within universes of different systems, but we cannot retain everything at the same stage or concentrate it. A good algorithm built for proper energy efficiency under an urban planning approach must understand the “ifs” as the path to good sustainable city development, and in conjunction with the surrounding cities.

An interesting example, as a case study, is to considerer a huge metropolitan region: Polycentric metropolitan areas

The European Rhine-Ruhr metropolitan region is a factual example. This region in the North Rhine-Westphalia Germany is considered to be one of the greatest powerful metropolitan cities in the world. It is an example of a polycentric metropolitan area, however, what is curious is that it is in the urban grid. There is no big city with metropolitan areas nearby; it is a cluster of big and bigger cities around, all with similar importance, independent of the number of population and with several cultural urban differences. The gross North Rhine-Westphalia GDP is the highest in Germany, but not the highest per person. However, a strong network provides for effective growth “(…) as it is the result of an agglomeration and urban sprawl of smaller urban centres that have ultimately produced the integration of a networked urban-system into a single metro-region.” (OECD, 2006, p.46)

This polycentric metropolitan area will be an interesting example for introducing the next chapter, but not for the population size, rather for the network and its importance.

The issue is not a city or a million small cities generating a lot of power, it is managing the power responsibly and having knowledge of all the variables.

4 THE ANSWER FOR A NETWORK TO *THE POWER OF A MILLION SMALL*

The truth about energy and city planning is that they do not work together at all. For starters, it is the only thing that is a real problem. Talking about resilience in cities, there are very ambitious beautiful programs like Masdar, effectively however they do not work as a whole.

The following discussion examines some energy and sustainable thoughts.

With bioclimatic or sustainability, both sciences have a triangle of three opposite vertexes. These principles are quite well known within the academic community, but not in regulations or planning directives. There seems to be an increasing distancing from reality, running the risk of building badly, instead of well. In order to answer some egocentric architecture, a house in a city means a lot less than we sometimes think, independently of the person who lives there, its size or its attributes. The total amount of power that the thousands or millions of buildings together with people, other kinds of life, culture or infrastructures generate, make any building insignificant.

Proceeding, why should a network of small or medium sized cities should be a possibility in order to compete against major cities if density, as we’ve seen in the first chapter, if not too much, is more effective to exergy conservation?

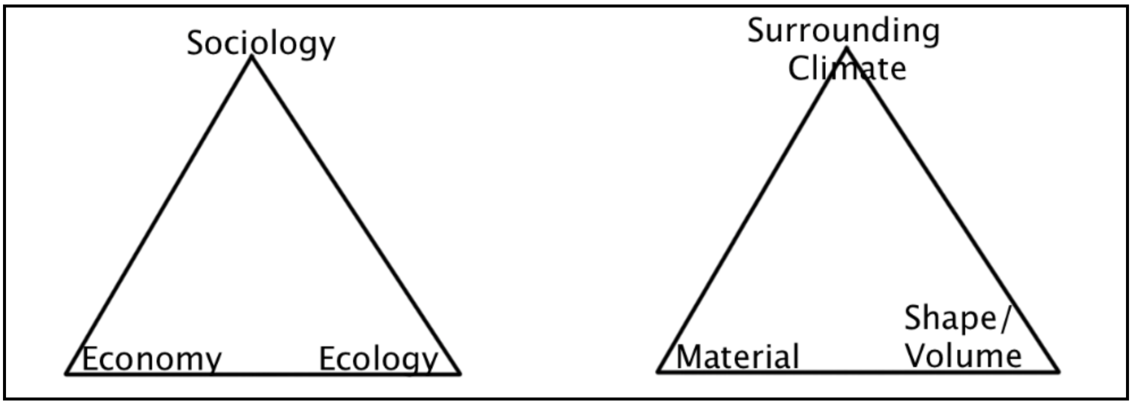

Figure 7. Triangle of Sustainability (left) and Triangle of Bioclimatic (right). In order to perform any sustainable or bioclimatic application, each of the three chapters must work together and comply the necessities of the each other.

Some interesting thoughts about Schumacher in his book *Small is Beautiful: as if people matter,* in chapter 5, *a question of size,* he criticizes some economical thoughts which still prevail nowadays like: the bigger the better. When Schumacher wrote this it was less visible, but nevertheless it was still obvious that most of the big countries were actually the poorest or less equal, while the smallest countries, like in Europe, were very rich and equal. This was not related to resources either, since nowadays the same issue occurs in other countries, an example being Mozambique, which has vast resources and is one of the poorest countries in the world.

Schumacher introduces us to the common theoretical processes of cultures or companies assemblage to a single strong unification which does not occur as had been believed, but instead the proliferation of nation states, or *balkanization* as he describes. It appears that a country, city or company likes its independence.

Lastly, the concept of economies of scale, quoting directly “Even today, we are generally told that gigantic organizations are inescapably necessary; but when we look closely we can notice that as soon as great size has been created there is often a strenuous attempt to attain smallness within bigness.” (Schumacher, 1975, p.68)

Schumacher give us the example of Mr. Sloan’s General motors leadership that structured the gigantic firm into “(…) a federation of fairly reasonably sized firms”. (idem, p.69) If we think about it and look closer at the re-structuring of the gigantic Portuguese energy company EDP, all units are independent entities (called as *Unidades de Negocio* like EDP Comercial S.A., EDP Distribuição S.A., or EDP Inovação S.A.), including financial independency, and it might be one of the biggest decisions the board has ever made in order to accomplish business success.

Reaching the right scale of a city, Schumacher, forty years ago, saw an adequate city size as between 500.000 people, but it cannot be limited in this way. This was not something he wanted to develop in his work so we need to understand his determination in the previous sentences.

The right city shape and size will surely not be the number of people, but rather how they connect as small, medium or big universes well integrated into the same system. But some things are certainly easy to understand, like a major city of 50.000 people who can practically know everybody and understand everything that is necessary. In a city with 500.000, that situation is much further from being possible since by that time, and growing a little bit more, it will be even harder, since local communities only base their decisions on the consultancy data and not on their life experiences with people.

Urban planners have been determining influence areas for placing landmarks, schools, bus stations or subways entrances for several years. There are several of different studies, but they always use the same variables: the way and time of movement. This particular index is very important for designing all city networks, not only the transport but also the services, public buildings, important rendezvous marks, tourism paths and security measures. But this index also helps to know how many people can exist in a certain area per square meter or hectare. Therefore, we must understand together with Schumacher’s examples that several steps from neighbourhoods, local communities, and villages to the general urban area can calculate great metropolitan areas. Influence studies will be simple interactions from a large algorithm determined by several contents. In those contents we certainly will have the energy issue to produce and conserve, to be as efficient as effective, but struggling within all other contents and different urban areas. It is necessary to start designing algorithms for systems that provide a network between different universes in which you can transfer the enough matter and energy.

Theoretically speaking, it will probably be impossible at an early stage for a million small cities, even very well connected, to grow much faster then major cities, if both have the same kind of culture and provisions. However, in time, and well planned, the million small cities can certainly become stronger and effective, without easily loosing certain principles like equity. This power of a million small networks is in fact a possibility and it in fact solves many problems that mass production creates in major cities: uncontrolled or controlled ineffectively. It is time to rethink the bioclimatic studies and their regulations in order to better re-shape our urban areas, create complex algorithms for different areas, which easily intersect. There certainly does not exist only one model for urban design, as well as existing only one model to design efficient energy or bioclimatic in buildings.

5 CONCLUSION – THE EPILOGUE

The only way to accept the possibility that a million small urban areas can produce and conserve more energy than a great city, with the same citizens, culture and provisions, is to provide a proper network urban plan. It is certainly possible to design an algorithm if a group of cities have different opinions, but it is impossible if they do not get along.

There is no right answer for city planning or efficient energy, but it would be important to avoid designing cities, which are to dense or simple plain cities. The same happens with too many great cities or simple small houses placed randomly. Urban areas are fundamental, it is insane to think otherwise, with the exception of farms and very few other situations. However, the size of these urban areas is really a matter about how they connect, in order to produce and rationalize together as a whole.

It is not only electricity or gas or petrol. It is not only about warm and cold. It is not only about some houses. It is about all of these together, taking away the selfishness of any individual that sees their house as the most important thing among his millions neighbours.

A house in a city is part of an environment. The environment as a system transfers energy everyday between air, between the ground, between the cables and pumps, but also between people. It is important that the different environments connect within each others sectors, and avoid concentrating all the power in few, unable to make equal standards, but very small richer individuals, and in the end, after so much efforts to save energy, they loose even more.

So, with so many different societies, from the concept of "megalopolis" to a conglomerate of small cities, there is a big difference of energy transferred and the right evaluation shall not be done superficially. The good network is essential for people's welfare as well as the necessary efficiency and effectiveness. The proper algorithm must go towards people and their environment needs, so that size does not matter, but people as the real target… they truly matter!

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Urban Regeneration - Developing strong sustainable urban design perspectives

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ABSTRACT: Contemporary Urban Regeneration (UR), as a comprehensive and integrated vision and action that looks for the long-lasting socioeconomic and environmental dynamism of the target areas, can offer the possibility to regenerate cities while simultaneously tackling sustainable urban development (SUD). This investigation explores achieving higher levels of sustainability trough an UR that focuses on a balanced set of sustainable and resilient urban design patterns. This investigation firstly addresses the concepts behind UR, while briefly accounting for its evolution. Secondly, it compares development strategies that procure higher levels of sustainability and resilience. Thirdly, with a shift from analysis to critical thinking, a framework for UR that focuses on achieving higher levels of sustainability is proposed. This investigation concludes that UR can strongly benefit from promoting higher levels of sustainability while addressing the capacity of urban environments to absorb recurrent disturbances, though retaining essential structures, processes and feedbacks, i.e., while promoting resilience.

1 INTRODUCTION

Modern-day cities have become the convenor pole of human activity, as the natural habitat of modern societies (Rogers, 1997, pp.2–24), reflecting the different behaviours and attitudes of human beings. Nevertheless, the growth of cities has been much greater than their societies' ability to reconvene urban environments (Abiko et al., 1995, p.44), while responding to new urban problems (Rogers, 1997, pp.2–24). Thus, contemporary UR is a *comprehensive and integrated vision and action for the resolution of urban problems and long-lasting improvement* (Governa et al., 2004, cit. in Ferreira, 2008, p.28) *in the economic, physical, social and environmental conditions of the target areas* (Roberts and Sykes, 2000, pp.17–20), which can help to create attractive places (Jones and Evans, 2008, p.1), while tackling sustainability and resilience issues and while responding to the needs of new economies and societies.

Contemporary UR has been identified as a crucial tool to promote SUD (Ferreira, 2008, pp.49–53; Roberts and Sykes, 2000, pp.17–20). Consequently, this investigation explores reaching higher levels of sustainability trough UR strategies that focus on introducing sustainable and resilient urban design patterns. This investigation first addresses the conceptual framework behind UR strategies, while briefly accounting for the evolution of urban planning that led to their rise. Secondly, also based on the prospect of promoting resilience, it accounts for the analysis of development strategies that both procure higher levels of sustainability and resilience. Thirdly, with a shift from analysis to critical thinking this investigation comprises the proposal of a readdressed framework for UR that focus on achieving higher levels of sustainability and resilience.

Though "*mankind's habitats*" - our cities - are the major destroyer of ecosystems and the greatest threats to human survival (Rogers, 1997, p.14), the twenty-first century is the "*era of the city*" (Tallon, 2009, p.7) and as such a sustained and resilient urban development is inescapable. Thus, one focuses on UR strategies that encourage higher levels of sustainability while promoting the capacity of urban environments to absorb recurrent disturbances and retaining essential structures, processes and feedbacks, i.e., while promoting resilience. Considering an application within UR strategies, a simplified support framework that comprises principles for sustainability and resilience enhancement is the main expected result of this investigation. One also concludes that UR can strongly benefit from the promotion of higher levels of sustainability, as these will comprehensively improve the target areas local dynamism and responsiveness.

2 PERCEIVING URBAN REGENERATION

Over the last decades, it has become hard to ignore the continual process of development that has characterised many inner city areas (Jones and Evans, 2008, p.1), which is profoundly transforming them, both in terms of their appearance and the ways in which we live and work in them. The current desire of local governments for regenerative interventions and for the "renaissance" of their cities is a defining feature of contemporary urban policy. As a result, UR has been given an increased public profile within many national policy agendas since the late 1990s and is of considerable public interest (Tallon, 2009, p.3; Ferreira, 2008, pp.11–13). The benefits of reinvesting in city spaces made redundant or derelict by years of neglect and abandonment are clear enough, according to Porter and Shaw (2009, p.2). They stress that there are good arguments for UR even in areas that, while still vital, have experienced sustained disinvestment.

UR is a comprehensive strategy (Roberts and Sykes, 2000, pp.17–20), that reinforces positive socioeconomic and environmental outcomes and helps to improve the ability of cities to meet the demands of new creative economies and societies. UR can become a main tool to promote SUD (Ferreira, 2008, pp.49–53; Roberts and Sykes, 2000, pp.17–20), offering an important opportunity to rectify past mistakes and create attractive places (Jones and Evans, 2008, p.1). One of the challenges of studying UR is that to understand its character it is necessary to consider the wider urban context within which it has come to the fore (Jones and Evans, 2008, p.4). As they point out, in the 1970s, cities in the western world suffered from the loss of traditional industries and from the rise of the new economy. Thus, across Europe, early assemblies of UR began as an attempt to ameliorate the negative effects of deindustrialization and enable cities to attract new investment (Jones and Evans, 2008, p.4,162; Tallon, 2009, pp.12–13).

The radical reorientation of urban policy in mid-1970s coincided with the acceleration of deindustrialization, the changing technological paradigm (Lago, 2007, p.64) and the turning point on the common consciousness over socioeconomic development and environmental concerns. The severe economic and oil crises of the 1970s led to an awareness about the environmental limitations of modern societies, which boosted the acceptance of a new paradigm (Pinheiro, 2006, pp.135–146). Two other aspects contributed to this change (Pinho, 2009, pp.38–39): (1) the critical review of the assumptions and results of *Modernism*, generated by theoretical changes and "*on-the-ground*" comparison; and (2) the "*discovery*" of the vital values of the traditional city, which had urbanistically been a "non-object". Consequently, it was only from the mid-1970s onwards that a real change in favour of the inner city took place (Pinho, 2009, p.95).

Urban planners then started to talk about the rehabilitation of urban areas (Lago, 2007, pp.62–63). From the late 1970s onwards, strategies shifted from "*negative policies*" (neglection, forced relocation and "*cleaning*") to more "*positive policies*", based on human rights, focused on individuals and adapted to local realities, such as "*in situ upgrading*" (Pinho, 2009, pp.97–98), "*rehabilitation*" or "*revitalization*". Urban interventions were redirected to promote the maintenance of existing urban fabrics and non-dominant urban concerns, such as socio-territorial exclusion, the environment and others, became part of the content of new urban policies and interventions (Ferreira, 2008, p.25). These processes began by promoting social, cultural, and economic change (Ferreira, 2008, p.26), while comprehending a widespread "re-imagination" of city centres, which involved physical enhancement and cultural animation processes and the transformation of cities' images (Short et al. cit. in Tallon, 2009, pp.20–21).

The late 1980s represented another turning point in urban development strategies as SUD began to be seen as a viable way to ensure the handover of contemporary environments, to future generations, while safeguarding their needs. This concept appeared in 1987, in the *Brundtland Report*, prepared by the World Commission on Environment and Development (Brundtland, 1987). This report highlighted the need for humanity to adopt a new model of life based on the interplay of three factors: economy, society and environment (Brundtland, 1987). This assumption paved the way for reconceptualisation of urban policies and interventions. During the 1990s there were more adjustments to the focus and operation of urban policies, recognising new problems and challenges. One of the most profound changes was the finding that urban policies should integrate environmental issues and contribute to SUD (Ferreira, 2008, p.26).

Thus, a new urban policy gained momentum - UR - breaking with previous intervention ideas (Cunha, 1999). UR does not sanctify all urban environments by the fact that they exist, but takes into account the given socioeconomic and environmental structure and shape of the city and the social fabric of socio-physical activities that such structures support and reflect, being sensitive to the symptoms of change in trends. Moreover, during the 2000s, three approaches to UR became apparent (Turok, 2005, cit. in Tallon, 2009, p.7). The "*urban renaissance*" agenda, subsumed within SUD, is concerned with physical and environmental conditions, promoting high quality urban design, mixed-use environments and sustainable cities (Tallon, 2009, p.7). The "*social inclusion*" agenda focuses on social conditions within deprived areas, encouraging the development of social capital and community participation (see Putnam, 2000; Kearns, 2003; Taylor, 2003, cit. in Tallon, 2009, p.7). The "*economic competitiveness*" agenda is concerned with improving economic performance and employment by increasing output, productivity and innovation (see Boddy and Parkinson, 2004; Buck et al., 2005, cit. in Tallon, 2009, p.7).

UR has become conventional wisdom within many governments and regeneration policies are being rolled out to catalyse the revalorisation of urban environments (Porter and Shaw, 2009, p.1). Given the scale of these challenges, it is easy to understand why UR has assumed such importance in the political agenda (Jones and Evans, 2008, p.162). Roberts and Sykes (2000, p.17) defined UR as "*a comprehensive and integrated vision and action which leads to the resolution of urban problems and which seeks to bring about a lasting improvement in the economic, physical, social and environmental conditions of an area that has been subject to change*". UR further constitutes a physical and a symbolic transformation in which, part and parcel of the process, is to reinvent the city for a new generation (Jones and Evans, 2008, p.4).

Roberts and Sykes (2000, pp.17–23) further define UR as an interventionist activity, that straddles public, private, voluntary and community sectors and is likely to experience considerable changes in its frameworks in response to socioeconomic, environmental, and political circumstances. Tallon (2009, p.8) has summarised the concerns of UR into five main subthemes: *physical environment* - it attempts to improve the built environment, through SUD concerns; *quality of life*: it seeks to improve the physical living conditions, cultural activities or facilities; *social welfare* - it endeavours the provision of basic social services; *economic prospects* - it seeks to enhance employment prospects, while attempting to recover the lost "economic flame"; and *governance* – it favours partnership, community engagement and multiple stakeholders.

Contemporary UR has been developed as a holistic concept for the socioeconomic and environmental transformation of affected urban areas, according to Jones & Evans (2008, p.4). They add that another key element of UR comprises the importance of changing a city's image. UR thus constitutes a physical and a symbolic transformation, as part and parcel of rebuilding a city lies on its reinvention city for a new generation. They further add that the focus of UR is not only on new environments, but rather on reforms to the existing ones, which part of making life better for people, while improving urban societies and communities (Jones et al. 2008:14).

3 SUPPORT FRAMEWORKS FOR URBAN REGENERATION

Urban environments have always played a crucial role to its inhabitants, users and visitors, given that the quality of life of urban citizens is directly influenced by the state of the environments they live in (Ferreira, 2008, p.50). According to the author, economic and population growth, as well as the elevated concentration of people and activities in urban areas, have created externalities, resulting in a set of environmental, social and economic issues. As such, most contemporary cities are confronted by common nuclei of problems not only of physical-ecological nature, but also of socio-cultural and economic nature. These issues are particularly complex since their causes are interconnected. The analysis of global urban development in the last decades has also been greatly influenced by the "*sustainability debate*" (focused upon the interplay between the environment and socioeconomic development) and the increasing recognition that urban societies are all part of one eco-system (Rogers, 1997, pp.25–63).

Thus, UR has arisen as a new way to tackle the problem of urban development and planning. Nevertheless, traditional UR has somewhat proven not be sufficient to fully achieve sustainable and resilient environments (Tallon, 2009, pp.159–163). Thus, in the final decades of the last century, a strong argument has grown up stressing the need for a more "*sustainable*" approach to urban development (Blowers and Pain, 1999, Polese and Stren, 2000, cit. in Thorns, 2002, p.204). To achieve "*sustainable*" UR and development, principles of sustainability must be incorporated in design (Tallon, 2009, p.166). This argument has led to the proliferation of several theoretical approaches that move towards the definition of balanced patterns of sustainability and resilience in urban environments, including *Sustainable Urbanism*, *Green Urbanism* and *Resilient Urbanism* (commonly denominated *Resilient Cities*), amongst others, which can further add insights to the contemporary framework of UR. These procedures for achieving higher levels of sustainability and resilience are discussed below.

3.1 *Sustainable Urbanism*

Sustainable Urbanism (SU) is a recent term prevalent in urban design and planning; within contemporary urban environments, it is rooted in the study of sustainability and urban design (Adhya et al., 2010, p.1). SU is a term and theory based on closing the loop on resources (Volkman, 2010, pp.257–258) and bring everything into the city. Sustainable Urbanism is about increasing the quality of life by bringing more resources within a short distance and increasing the quality of products that are offered. SU has recently been defined as "*walkable and transit-served urbanism integrated with high performance buildings and high-performance infrastructure*" (Farr, 2008, p.42). *Compactness* (density) and *biophilia* (human access to nature) are considered as the core values of SU (Farr, 2008, p.42; Adhya et al., 2010, p.2).

The defining elements of SU are: (1) *compactness* – it promotes compact development, minimum development densities, increased population density, people's willingness to walk and use and seeks to integrate infrastructure design increase with density; (2) *biophilia* – it promotes the connection between humans and nature, linking open spaces, sustainable food production and agricultural practices with human concerns; (3) *sustainable corridors* – it promotes corridors that connect one area to another efficiently, provide biodiversity and wildlife support and allow people to travel in a sustainable manner; (4) *high performance buildings* – it encourages energy efficiency, clean energy resources, improved indoor environments, source reduction, pollution prevention, recycling, multi-functionality, component optimisation and integrated design within buildings; and (5) *high performance infrastructure (*street, sidewalk, utilities and infrastructures, landscapes, and streetscape elements*)* – it endorses component optimization (maximised performance, minimised environmental impact, efficient use of materials and extended lifecycle), multifunctional optimization (minimized conflicts among parts and promotion of synergies) and integrated design (systems-oriented design focused on the entire urban infrastructure).

3.2 *Green Urbanism*

Green Urbanism (GU) is a conceptual model for zero-emission and zero-waste urban design, which arose in the 1990s, promoting compact energy-efficient urban development, seeking to transform and re-engineer existing urban areas and regenerate post-industrial city centres (Lehmann, 2010, p.1). According to Beatley (2000, pp.6–9), the vision of GU promotes cities that: (1) strive to live within their ecological limits, reduce their ecological footprints, and acknowledge their connections with and impacts on other environments; (2) are green and designed in ways analogous to nature; (3) strive to achieve a circular metabolism; (4) endeavour local and regional self-sufficiency; (5) facilitate and encourage sustainable, healthful lifestyles; and (6) emphasize a high quality of life and the creation of highly liveable communities.

Lehmann (2010) has summarised the defining elements of GU: (1) *climate and context* – it enhances the opportunities offered by local climate and context; (2) *renewable energy* – it promotes renewable energy sources; (3) *zero waste* – it endorses zero-waste planning; (4) *water* – it encourages water efficiency, rainwater collection, waste water recycling and storm water harvesting; (5) *landscape, gardens and biodiversity* – it endorses green spaces preservation and enhancement and farming/agriculture; (6) *sustainable transport and good public space* – it promotes compact and poly-centric cities with sustainable transports and bicycle or pedestrian-friendly environments; (7) *local and sustainable materials* – it encourages using regional and local materials, with less embodied energy and pre-fabricated modular systems; (8) *density and retrofitting of existing districts* – it promotes retrofitted districts, urban infill, and densification strategies; (9) *green buildings and districts* – it encourages passive and green design principles; (10) *liveability, healthy communities and mixed-use programmes* – it encourages affordable housing, mixed-use programmes and healthy communities; (11) *local food and short supply chains* – it promotes high food security and urban agriculture; (12) *cultural heritage, identity and sense of place* – it promotes sustainable cities with resilient communities, public space networks and modern facilities; (13) *urban governance, leadership and best practices* – it promotes best practices for good urban governance; and (14) *education, research and knowledge* – it sponsors technical training, up-skilling, research, exchange of experiences and knowledge dissemination (the 15th element reports to urban strategies in developing countries).

3.3 *Resilient Urbanism*

Resilient Urbanism (RU) is, in simple terms, a type of urbanism that promotes Resilient Cities (RCs). A RC is one that has developed capacities to help absorb future shocks and stresses to its social, economic, and technical systems and infrastructures so as to still be able to maintain essentially the same functions, structures, systems, and identity (Applegath et al., 2013). Applegath et al. (2013) further propose the following as an overarching set of principles for endorsing urban resilience: (1) *diversity* – increase the multiplicity of urban systems that, encouraging the ability to thrive, survive and bounce back from external shocks and stresses; (2) *redundancy* – increase redundancy of key urban components; (3) *modularity and independence* – promote system components independence and modularity; (4) *feedback sensitivity* – encourage the detection and response to changes in system constituent parts; (5) *capacity for adaptation* – promote the adaptability of key urban components; (6) *environmental responsiveness and integration* – promote responsiveness and integration of components and functions with built environments, services and resources.

Applegath et al. (2013) also put forward the defining elements of RU: (1) *density, diversity and mix* – it embraces density, diversity and mix of uses, users, building types and public spaces; (2) *pedestrian priority* – it prioritizes walking as the preferred mode of travel; (3) *transit supportive* – it is transit supportive, promoting the shift from car oriented to transit oriented urban patterns and developments; (4) *place-making* – it focuses on conserving, enhancing, and creating strong, vibrant places, which are significant components of the city’s structure and of the community’s identity; (5) *complete communities* – it promotes resilient, pedestrian-friendly environments with reduced carbon footprint; (6) *integrated natural systems* – it promotes conserving and enhancing the health of natural systems, while managing the impacts of climate change; (7) *integrated technical and industrial systems* – it enhances the effectiveness, efficiency and safety of technical and industrial systems and processes to increase energy efficiency and reduce environmental footprint; (8) *local sources* – it promotes growing and producing the resources needed, in close proximity (200 km radius); (9) *engaged communities* – it requires the active participation of community members; (10) *redundant and durable life safety and critical infrastructure systems* – it plans and designs for redundancy and durability of their life safety and critical infrastructure systems; and (11) *resilient operations* – it develops building types and urban forms with reduced servicing costs, and reduced environmental footprints.

These procedures - *SU, GU, RU* - are neither disjoint nor completely overlapped. They are complementary. UR, as a comprehensive strategy, vision and intervention for urban improvement should take into consideration all three approaches, in order to promote sustainable and resilient urban environments. Thus, the following section of this investigation comprises the proposal of a readdressed support framework for UR. This framework does not necessarily cover all the common subjects and issues of UR, given that its main purpose is to support and extend existing UR frameworks. Moreover, this framework is based exclusively on the three procedures studied. As such, this framework should be interpreted as an on-going project, of which this article and the presented framework are a preliminary version.

4 A SUSTAINABLE SUPPORT FRAMEWORK FOR RESILIENT URBAN REGENERATION

"*Cities are the defining ecological phenomenon of the twenty-first century*" (Newman and Jennings, 2008, p.2). They have become the main engines of economic growth and the places where humanity dwells. Thus, based on the previous analysis and impending concepts of sections 2 and 3, one has readdressed and designed a support framework for UR, whose ultimate goal is to tackle this urban phenomenon by promoting higher levels of sustainability and resilience - *Sustainable support framework for resilient Urban Regeneration* (SFUR).

SFUR comprehends two main principles: (1) "*urban sistematology*" and (2) "*urban resilience*". Consequently, SFUR firstly implies understanding (1) *the city as an ecosystem ("urban sistematology")*. Here, the *ecosystem viewpoint* is an inclusive one that sees humans as part of local socio-ecological systems, from bioregions to the biosphere, in which the focus is on connections and practices that support life in its numerous forms (Newman and Jennings, 2008, p.4). Moreover, based on Beatley's (2000, pp.6–9) principles of "*green cities*", one further defines three sub-conditions of (1) "*urban sistematology*": (1.1) a circular urban metabolism; (1.2) urban ecological limits that reduce ecological footprints and acknowledge urban connections with and impacts on other environments; and (1.3) local and/or regional self-sufficiency.

Table 1. Sustainable support framework for Resilient Urban Regeneration (SFUR)

area	criteria	measures and actions
physical environmental enhancement	compactness (1)	promote compact development, minimum development densities, increased population density, pedestrian-friendly environments and infrastructure density;
	biophilia (2)	sponsor the connection between humans and nature - linking open spaces, encouraging green urban environments, designed in ways analogous to nature, endorsing green spaces preservation and enhancing the health of natural systems;
	energy (3)	promote renewable energy sources and energy efficiency within the urban system, through a circular metabolism perspective;
	water (4)	encourage water efficiency, rainwater collection, waste water recycling and storm water harvesting within the urban system, through a circular metabolism perspective;
	local sources (5)	boost the usage of regional and local resources, with less embodied energy and promote growing and producing the resources needed, in close proximity;
	waste (6)	endorse zero-waste planning, integrated recycling and natural waste disposal processes;
quality of the milieu	place-making (7)	safeguard and enhance cultural heritage, identity and sense of place, promote public space networks and modern facilities and focus on conserving, enhancing, and creating strong, vibrant places, which are significant components of the city and the community;
	high performance buildings (8)	encourage enhancing the opportunities offered by local climate and context, energy efficiency, clean energy resources, improved indoor environments, source reduction, pollution prevention, recycling, multifunctionality, reduced servicing costs, component optimisation and integrated design within buildings and urban districts;
	high performance infrastructure (9)	endorses component optimization, multifunctional optimization, integrated design and promote redundant and durable life safety and critical infrastructure systems;
social welfare	community enhancement (10)	improve the provision of basic social services while emphasising a high quality of life, creating highly liveable communities and encouraging sustainable, healthful lifestyles;
	friendly communities (11)	promote compact and poly-centric cities with sustainable transports and bicycle or pedestrian-friendly environments with corridors that connect one area to another efficiently, provide biodiversity and wildlife support and allow people to travel efficiently;
economic prospects	diversity and mix (12)	encourages different types of housing, mixed-use programmes and environments, and mix of users, building types and public spaces;
	integrated systems (13)	integrated technical and industrial systems – it enhances the effectiveness, efficiency and safety of technical and industrial systems and processes to increase energy efficiency and reduce environmental footprint;
	education (14)	sponsor technical training, up-skilling, research, exchange of experiences and knowledge dissemination;
urban governance	governance (15)	promote best practices for good urban governance;
	participation (16)	encourage the active participation of community members.

Furthermore, to fully secure (2) "*urban resilience*", and *effectively promote resilient urban environments*, the following factors, as suggested by Applegath et al. (2013), are present and implicit throughout the application of SFUR: (2.1) *diversity* – increased multiplicity of urban systems (2.2) *redundancy* – increased overlapping of key components; (2.3) *modularity and independence* –

promote components independence and modularity; (2.4) *feedback sensitivity* – encourage the detection and response to changes in the system; (2.5) *adaptability* – promote the capacity for adaptation of key components; (2.6) *responsiveness and integration* – promote responsiveness and integration with environments, services and resources. The following table resumes SFUR and systematises the relationships between the areas, criteria, measures and actions of the framework.

SFUR furthermore comprehends five main areas, following Tallon's (2009, p.8) approach (*physical environmental enhancement*, *quality of the milieu*, *social welfare*, *economic prospects* and *governance*), which are then sub-divided into specific criteria (*compactness*, *biophilia*, *energy*, *water*, *local sources*, *waste*, *place-making*, *high performance buildings*, *high performance infrastructure*, *community enhancement*, *friendly communities*, *diversity*, *education*, *integrated systems*, *urban governance* and *community participation*).

The five proposed areas of SFUR are not mutually exclusive, but interconnected, as successful UR strategies should recognise the linked nature of socioeconomic and environmental problems in the context of local geographies (Tallon, 2009, p.5). There are inherent weaknesses to approaches to UR that are "short term, fragmented, ad hoc and project-based without an overall strategic framework for city-wide development" (Hausner, 1993, cit. in Tallon, 2009, p.5). Due to its nature and practice (Tallon, 2009, p.5), UR is far from being a completely fixed set of guiding procedures and practices. Thus, this investigation has tried to contribute to the UR agenda, by providing a new set of guiding principles that procure higher performance levels.

In this context, the aforementioned procedures and more specifically this SFUR can provide an additional set of guiding principles that can complement existing UR framework(s). Theoretical approaches that move towards the definition of balanced order patterns in urban environments, that promote higher levels of sustainability and resilience, can provide the bases for conceiving new holistic and comprehensive interventional procedures, thus providing a broader theoretical support to the overall panorama of UR. Moreover, procedures such as this SFUR, should be thought of as on-going interventional support for UR and, therefore, should be redefined and adjusted according to local, regional, and national contexts, therefore providing an integrated and adapted set of guiding principles.

5 CONCLUSION

UR has been given an increased public profile within national agendas and has become of considerable public interest. It has been identified as a fundamental tool to promote SUD. UR is understood as a comprehensive and integrated vision and action that seeks to bring about a long-lasting improvement in the socioeconomic, physical and environmental dynamism of the target areas. UR should promote an effective SUD, offering the opportunity to rectify past mistakes and create attractive places that further sustain higher levels of sustainability and resilience. Nevertheless, traditional UR has proven not be sufficient to fully achieve sustainable and resilient environments. However, the proliferation of several theoretical approaches that move towards the definition of balanced patterns of sustainability and resilience in urban environments, including Sustainable Urbanism, Green Urbanism and Resilient Urbanism, has offered the possibility to readdress UR in order to achieve higher performance levels.

This investigation has addressed and compared the theoretical approaches mentioned above and established a basis for a SFUR. These procedures are neither disjoint nor completely overlapped, but complementary. As such the proposed SFUR is based on their complementarity. The proposed SFUR does not cover all the common subjects and issues of UR, given that its main purpose is to support and extend existing UR frameworks and is a first attempt in doing so and an on-going project. The developed SFUR comprehends two essential principles: (1) "*urban sistematology*" and (2) "*urban resilience*" and four main areas, sub-divided into sixteen criteria. It was designed according to an ecosystem viewpoint approach, which sees humans as part of local socio-ecological systems and focuses on the relationships and processes that support life in its myriad forms, and allow the development of higher levels of sustainability.

In this context, the aforementioned procedures and more specifically this SFUR can provide an additional set of guiding principles that can complement existing UR framework(s). Theoretical approaches that move towards the definition of balanced order patterns in urban environments, that promote higher levels of sustainability and resilience, can provide the bases for conceiving new holistic and comprehensive interventional procedures, thus providing a broader theoretical support to the overall panorama of UR. UR can strongly benefit from the promotion of higher levels of sustainability, as these will comprehensively improve the target areas local dynamism and further enhance their ability to withstand future stresses or changes, while maintaining a coherent and comprehensive path towards sustainability.

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Nearly Zero Energy applied to urban zones – Main challenges and perspectives

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ABSTRACT: The introduction of Nearly Zero Energy Building by the Directive 2010/31/EU on energy performance of buildings induces a new paradigm. Buildings do not exclusively belong to the demand side of the energy system anymore; it becomes a source of electricity generation and thus equally part of the supply side. This new perspective makes wonder the pertinence of enlarging the concept of Nearly Zero Energy to urban scale. The article will discuss which would be the technical and economic implications and challenges of this change of scale, firstly considering the advantages concerning building and system factor, the ones to which the current trend are fostered, and then widening the analysis to morphology and transport consumption, that seem to have the power to further enhance the potentialities of Nearly Zero Energy.

1 INTRODUCTION

The European Union targets ambitious commitments; namely reduced energy consumption, cutting greenhouse gases (GHG) by at least 20% of 1990 levels for 2020 and even higher for 2050, 80-95% below 1990 levels (EC 2010).

Since buildings account for around 40% of total primary energy and 36% of CO_2 emission in Europe (Atanasiu 2011), the reduction of energy consumption and the use of energy from renewable sources in the building sector constitute important measures needed to reduce Union's energy dependency and GHG emission, thus achieving defined goals.

1.1 *From Nearly Zero Energy Building to Nearly Zero Energy Urban Zones*

The Directive 2010/31/EU on the energy performance of buildings (EPBD) (EU 2010) introduces Nearly Zero Energy Buildings (NZEB) that are buildings "that have a very high energy performance, which zero or very low amount of energy required, should be covered to a very significant extent by energy from renewable sources, including energy produced on-site or nearby". The directive fixes the deadline for the implementation for all new buildings and major renovations by 2019 for all public and by 2021 for all private buildings.

Some main challenges of this new approach are the "very low amount of energy" required by the building, thus focusing on the implementation of passive solutions, the "significant extent of energy by renewable sources", in order to reduce emission through cleaner sources, and the "production nearby", with the aim to reduce the dependence from the grid. It's important to remark that the energy considered by the definition, is only the operational energy consumption. It does not include the incorporated energy of the materials, which nevertheless is a notable amount of the total consumption.

The directive also underlines the importance of cost-effectiveness, stating that the NZEB minimum energy performance requirements, which should be specified at national level, should be set considering cost optimal levels. They should be found in the range of performance levels where the cost benefit analysis, calculated over the estimated economic lifecycle, is positive.

There are two aspects within the definition of NZEB that make wonder the pertinence of enlarge the concept of Nearly Zero Energy to urban scale. Firstly, NZEB initiate a change of paradigm, indeed such buildings do not exclusively belong to the demand side of the energy system anymore but become source of electricity generation, and thus equally part of the supply side (Koch & Girard 2011). The energy balance at urban scale could promote the use of more efficient technologies, since the clustering of buildings affects greatly the opportunities for and costs of decentralized supply systems (IPCC 2007). Secondly Nearly Zero Energy performance level is not yet cost optimal with current prices, as shown by the Federation of European Heating, Ventilation and Air-conditioning Associations (Kurnitski et al. 2011), so the change of scale could be a challenge to achieve cost optimality with current market prices.

Going beyond the current trends, which foster only the efficiency of the energy systems, as heating and electricity production, and buildings, passive solutions as insulation and glazing (Salat & Bourdic 2012), the urban scale seems to further enhance the advantages of Nearly Zero Energy. As shown by studies about European Cities, like London, Toulouse and Berlin (Ratti et al. 2005) or Paris (Salat 2009) urban morphology can play a factor 2, being potentially able to reduce by itself the consumption by 50%.

Moreover when considering the urban area, and including transport, the final energy consumption increases from 40% to 71% of the total European consumption (ADEME 2012). So including transport consumption in the boundaries of Nearly Zero Energy would trigger significant reduction in GHG emission.

The following section will discuss how the concept of Nearly Zero Energy could benefit from the enlargement of scale both in the reduction of emission and costs. Firstly will be point out the advantages at building and system level, and then, widening the approach, the implications of morphology and transport.

2 POTENTIALITIES OF BUILDING AND SYSTEM FACTOR

2.1 *Fostering alternatives strategies*

On supply side the assessment of the single building will fail to consider certain measures or technologies, which are not applicable, either for technical or for economic reasons, to small consumers (Koch 2009). It is only by combining a number of consumers to one bulk buyer that technologies, widely promoted by European Union, as district heating, cogeneration (CHP), trigeneration, biomass, and solar energy, can provide alternative strategies, as pointed out by Nast (2004).

Although CHP can be small enough to supply single buildings, for example through microturbine, it’s only with huge CHP that better efficiency can be achieved with lower costs and CO_2 emission released (Woods et al. 2005). Waste woods biomass systems can be cost effective only with the increasing dimension of the system, while concerning solar thermal, a great contribution could be given by releasing in winter the heat accumulated during the summer. This solution can be economically viable only through a huge seasonal thermal storage, which is available only when clustering buildings (Nast 2004).

The new scale so enables new technologies and strategies with higher efficiencies, e.g. CHP, and lower cost investment, thus easing the cost effectiveness of the solution and reducing GHG emission.

2.2 *Alteration of consumption pattern*

The consumption pattern is another variable indispensable to design the optimal power generation capacity and thus influencing the cost of the system.

As explained by Willis & Scott (2000) and shown in figure 1, individual consumption is unpredictable, and its fluctuations along the day is unrevealed. The behavior of the single household seems fortuitous. This appearance is caused by the inconsistent individual use of household appliances for short periods (Paareto 2009). However when more households are aggregated, clear consumption pattern seems to emerge and the total consumption is smoothen (fig. 1) thus reducing the power needed of the supply system.

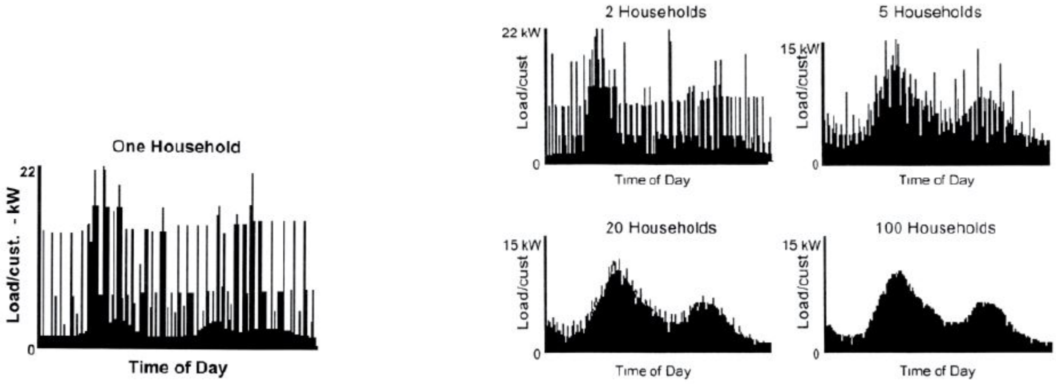

Figure 1. Consumption pattern with the increasing number of households (source: Willis & Scott 2000)

Further advantage consists in the temporal resolution. Reducing the discrepancy between highest and lowest load the necessity to store the energy, to compensate the fluctuation, is reduced. This influences relatively the electricity generation, since feed-in tariffs allow electricity energy export, but it strongly affects thermal production, which needs a tighter temporal match between conversion and use to avoid the need for large storage capacities (Koch & Girard 2011).

The enlargement of the scale, with the smoothing of peak load, has thus a great technical, financial and environmental impact due to the reduced power of the system and size of the storage.

2.3 *Triggering economy of scale*

The enlargement of scale fosters the cost optimal level, which is a target of the EPBD for NZEB but, as argued by Kurnitski et al. (2011), is not yet cost optimal with current prices. A better chance to reach cost optimality at urban scale is suggested by the fact that the increased scale is linked to a bulk purchase of building materials, which would inevitably reduce the purchase price.

A European market research conducted by EPIA (2012) shows how the price of photovoltaic panels, that is between 1700 and 2300 €/kWp for a system between 3-10 kWp would reduce to 1250-1800 €/kWp for a purchase of 500kWp with a reduction between 22 and 26%. An analogous study (Schnauss 2008) has shown even higher economy of scale for solar thermal with reductions from 650-700 €/m^2 for a system of 10m^2 to 350-480 €/m^2 for surfaces of 50m^2.

The economies of scale of passive solutions, external thermal insulation system (ETICS) and glazing, have been assessed resorting to a generator of price (CYPE 2013), available in Portugal, that takes into account the concrete characteristics of the specific project, thus underlining the variation in prices with the increasing of the dimension of the investment. The simulation has been run comparing a semi-detached house, with a floor area of 300 m^2, with a neighborhood with a floor area of 30000m^2, for around 500 inhabitants, composed by 100 similar houses in row (fig. 2). The results showed how for the semi-detached house a 5 cm ETICS would cost 66,8 €/m^2 while a PVC framed window system would cost 237€. With the considered size of neighborhood instead, they would cost respectively 50,6€/m^2 and 181€ with a reduction of 23-24%.

What interests about this analysis is not the price in itself, which varies depending from the peculiarity of the national market, but the economy of scale that it highlights, which is anything but negligible, and that could help to achieve cost optimality.

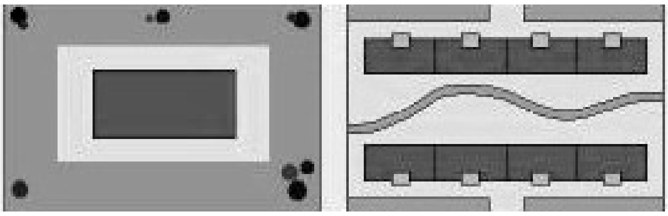

Figure 2. Scheme of the semi-detached house and the neighborhood with row houses considered for the simulation with the generator of price (source: CYPE 2013).

3 POTENTIALITY OF MORPHOLOGY

The potentiality of the assessment of the urban scale does not deplete to the building and system level. Urban morphology is a parameter that strongly affects the consumption. Some of the key parameters, as will be discussed further, are the shape of urban canyon, the shape of buildings and the density of the settlement.

3.1 *The factor 2 of morphology*

Salat (2009) has shown how considering different urban fabrics, and keeping identical all the other characteristics, modernist texture consumes 1,8 times more than traditional Paris urban block (fig. 3), thus confirming previous studies conducted by the University of Cambridge and Massachusetts Institute of Technology that suggest that urban morphology can play a factor 2 in reducing building energy consumption.

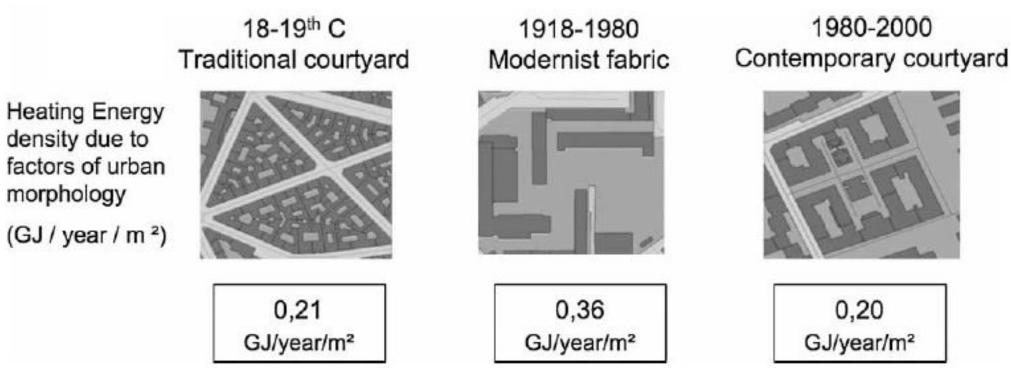

Figure 3. Effect of urban morphology on the energy need of building stock in Paris (source: Salat 2009).

This reduction in consumption is related to the fact that morphology affects the microclimate of the urban area, influencing wind flows and heat island effect, and heating, cooling and artificial lighting needs, through shape factors and percentage of solar radiation reaching the façade.

3.2 *Shape of urban canyon*

Oke (1981) found a relationship linking street geometry and climate effect. It shows how the maximum variation of temperature of the air between the urban area and the rural area outside the settlement ($\Delta T_{u\text{-}r\ (max)}$) increases with the raising of the ratio between height of the building (H) and width of the street (W), or alternatively with the reduction of the sky view factor ψ_{sky} (fig. 4). The increase of air temperature influences the heating and cooling consumption. Whether it is desirable or not will depend on the background climate. In cold countries the heat island effect would reduce the heat needed while in warmer countries may produce stressful condition.

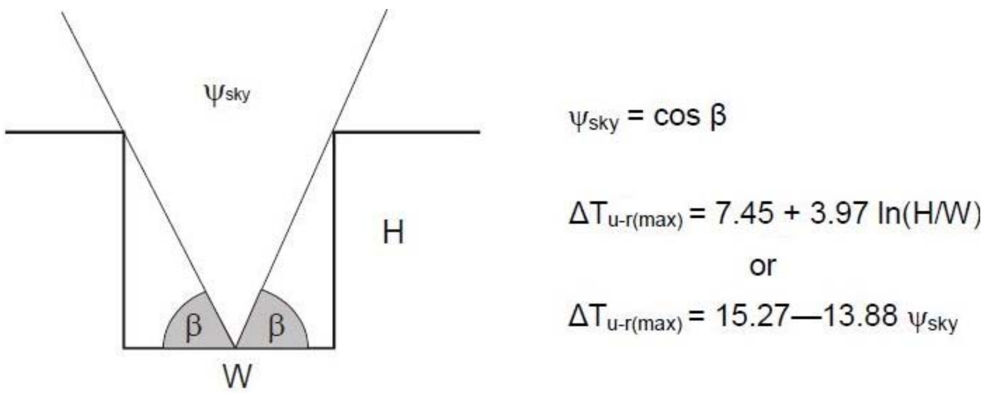

Figure 4. Correlation between heat island and shape of the street canyon (source: Mills n.d., Oke 1981).

3.3 *Shape parameters of buildings*

The shape of buildings is another aspect strictly related to energy consumption. Two core parameters are the (1) surface-to-volume ratio or compacity (March 1972) and the (2) ratio of passive-to-non-passive zones (Ratti et al. 2005). These parameters, despite could appear to be linked to the design of the single building, since they depend on its shape, are considered as urban morphology variables, being strongly bound to the regulation introduced by urban planning instruments.

$$Compacity = \sum \frac{S}{V^{2/3}} \tag{1}$$

$$Passive\ Ratio = \frac{\sum PassiveVolumes}{\sum BuiltVolumes} \tag{2}$$

The compacity is relevant to energy consumption of building since it represents the amount of surfaces exposed to the outside environment (S), which is responsible for heat losses. Passive zones percentages measure the potentiality of the building to use passive resources as daylight, sunlight and natural ventilation. All the perimeter zones of a building lying within 6 meters of the facade, or twice the ceiling height, are classified as passive while all other zones are considered non-passive (Salat 2009). These two parameters have to be considered carefully because minimizing the compacity would minimize heat losses but would simultaneously reduce the possibility to exploit sunlight, while maximize the passive ratio would have the opposite implication.

Ratti et al. (2005) suggest that passive to non-passive ratio is a better indicator of energy consumption. Through a simulation, with a digital elevation model (DEM), a comparison between three case study cities of London, Toulouse and Berlin and keeping equal all the parameters not linked to morphology they showed how heat losses through the building envelope are not the most prominent component of the total energy budget, and the possibility to benefit of passive sources as daylight and natural ventilation have a greater influence. The results underlined how passive surfaces present a significant reduction in energy consumption, almost 50%, compared to non-passive surfaces.

These results are not absolute truth. The simulation conditions influence them, so in countries with more extreme winter conditions than United Kingdom the heat losses can dominate, while southern location could further benefit from passive gains.

3.4 *Density*

Density is another parameter, set at urban planning level, which influences consumption and cost of the infrastructures. Multi-family buildings have lower energy use than single-family houses, as shown in figure 5.

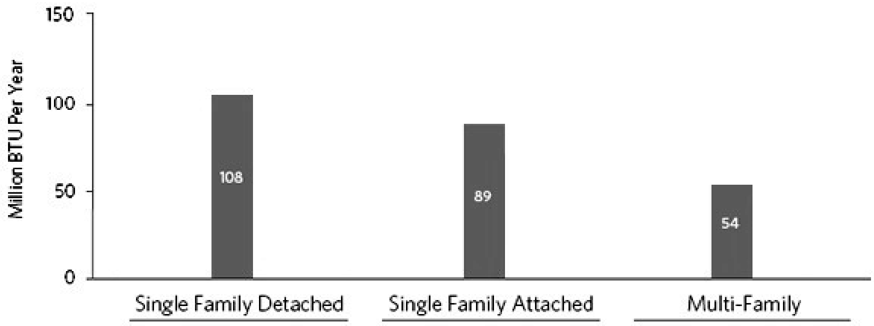

Figure 5. Energy requirement variations in different housing type (source: EPA 2011)

Density furthermore influences the applicability of efficient technologies in district heating and the cost of the infrastructure. Higher density of urban area results in a relatively higher heat demand density and therefore is favorable for the financial viability of heating networks so that there is a negative correlation between density and cost for this type of infrastructure including the operation. In this way become profitable CHP, with higher efficiency than separate power-heat generation, that are usually oriented to meet the heat demand and not towards a specific power outputs, and so are dependent on a high density of heat demand (Koch 2009).

The purpose of this section is not to propose universal solutions, since an answer would not suit to all the cases, but is to understand the importance of minimal thresholds that have to be taken into consideration since they strongly influence the energy consumption. In the EU's targets of reduction of GHG emission the potential of a factor 2 cannot be overlooked, and so it's important to understand which are the parameters that need to be corrected and how they influence consumption.

This factor 2 can be triggered only if it is controlled at urban scale before than at individual building, since urban planning defines the rules for building design. Wrong choices taken during the urban planning process affect the choices when designing the building. This is another reason why the possibility to enlarge the concept of NZEB to urban area should be considered.

4 INCLUDING TRANSPORT IN NEARLY ZERO ENERGY

The NZEB definition, being focused on building level, does not include the assessment of transport emission. However when enlarging the scale to urban level it seems inescapable wondering if also transport should be included in the boundaries of Nearly Zero Energy definition. In fact the European final energy consumption increases from 40%, for buildings, to 71% when considering the urban scale, with a 31% of the consumption due to transport (ADEME 2012).

4.1 *Morphology's influence on travel behavior*

A question that rises when passing to urban scale is: as urban design through urban morphology, influences building consumption, can it also influence transport consumption?

Many studies have shown how density and mixed uses can strongly influence travel distance and modal choice. Newman & Kenworthy (1989) discovered that transport energy is linked to density and that fuel consumed for individual vehicles per inhabitant is an inverse function of demographic density.

Mixed-use pattern favors the reduction of distance between facilities, since they imply the opportunity to allocate local facilities and services as groceries, stores, primary schools, kindergarten and workplaces in the area, since the catchment guarantees a sufficient number of users to make it economically viable. This reduction of distance between facilities determines a decrease in car usage (Van and Senior 2000) and facilitates non-motorized means (Naess & Jensen 2002) encouraging cycling and walking (Thorn & Filmer-Sankey 2003), thus not reducing only the travel distance, but also influencing the modal choice of transportation.

Sustainable neighborhoods that focus on high density, mixed use and pedestrian and cyclist friendly environment through traffic calming measures as Vauban, in Freiburg, and Bedzed, in

Sutton, testify outstanding reduction of distance travelled by car, confirming the assumption of the more theoretical studies. A survey conducted in 2002 in Vauban, showed that 70% of the trips are done using public transport, walking and cycling, with only 30% of the trips are covered by car (Broaddus 2010). Monitoring in Bedzed has shown reduction of 65% on distance travelled by car compared to national average with car ownership 0,61 per household while the national average is 1,0 (Lazarus 2003).

The dependence of travel modal choice from density, mixed use and proximity shows how urban design can have a substantial impact on private car usage thus reducing consumption and CO_2 emission. The authors suggest that if the change of scale suggested is desired, the opportunity to include transport emission in the boundaries of Nearly Zero Energy should not be missed.

5 CONCLUSION

The paper analyzes the Nearly Zero Energy concept and factors that highlight its extended application to urban zones. The main challenge in buildings is to achieve Nearly Zero Energy with optimal cost. The Nearly Zero Energy Urban Zone main challenge is to put this option into the agenda and identifies the balance that urban scale can draw to achieve that.

Even taking into account only the two factors considered by actual trends, the building and system factor, the enlargement of scale shows technical and economical potentialities to reach Nearly Zero Energy, thanks to the availability of different technologies, not suitable implemented in the single building, and to the economy of scale that the dimension can trigger.

Urban scale, however, reveals more clearly its whole potentialities when the analysis is broadened, and it’s assessed also the impact of urban morphology, that strongly impact not only building but also transport consumption. A potential reduction of 50% of building consumption cannot be underrated particularly considering that is potentially for free. A better design of urban space in fact, choosing for example a proper passive ratio would not imply an increase of cost regardless.

The way to Nearly Zero Energy applied to urban scale nevertheless is anything but unobstructed. As point out by Koch (2009) the increasing number of buildings considered in the energy balance would raise complexity in calculation. Also the increased number of actors and stakeholders involved could be another limiting factor. The coordination between different stakeholders could slow down the process for the presence of conflicting interests.

However considering the tight binding targets set by EU for 2020 and 2050 and that the urban scale, beyond contributing to reduce GHG emission, could be a challenge to reach cost optimal level, the article suggests that the energy balance assessed at urban level could be an instrument to grasp the full technical and economic potential of Nearly Zero Energy.

The article therefore suggests the need of a further and more detailed discussion about the opportunity of including the urban scale in Nearly Zero Energy definition and about its boundaries.

Further development in future works should focus on understanding which is the proper dimension of the urban zone, in order to be large enough to benefit from the advantages of the new scale without raising to much the complexity, and valuating with more detail which are the implications and difficulties of including transport in the boundaries of Nearly Zero Energy. These seem to be key aspects to assess the viability of this change of scale.

They should also study which are the social implications, since the urban scale includes also a social nature. Among the spatial attributes, investigating not only technical but also social characteristics, the Nearly Zero Energy applied to urban zones could provide a platform to promote a sustainable urban development (Koch 2009).

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ICT supporting energy efficiency improvements in urban and rural neighbourhoods

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ABSTRACT: Energy efficiency is an increasingly important issue in the built environment for both urban and rural areas of Europe. To date the focus has been typically at the building level, but is increasingly concentrating on broader systems, such as neighbourhood and city levels. Information and communications technology (ICT) can significantly contribute to the energy efficiency of neighbourhoods through a range of systems, tools and solutions. Achieving truly energy efficient neighbourhoods requires a holistic approach to include all the energy systems of a neighbourhood, such as buildings, infrastructure, transportation, energy distribution and production, as well as the involvement of citizens. All these areas have an impact on energy efficiency, and it can be supported by ICT in the following technology areas: 1) planning, designing and operation, 2) decision support, 3) energy management, and 4) integration technologies. This paper presents the key findings of IREEN (ICT Roadmap for Energy Efficient Neighbourhoods) project funded by European Commission's 7th Framework Programme.

1 INTRODUCTION

1.1 *The scope of the paper*

In this paper energy efficiency is discussed from holistic point of view, meaning that the entire energy chain from sustainable energy production and distribution to the efficient energy demand is considered. Energy efficiency at the neighbourhood level is increasingly focused for both urban and rural areas in Europe with the majority interested in improving their neighbourhoods' energy efficiency through various development projects in both new and existing areas. This paper presents the ways information and communications technology (ICT) can contribute to the future development in the planning and operation of a range of neighbourhood systems. Achieving truly energy efficient neighbourhood requires co-operation and communication between the different of stakeholder groups and associated energy systems.

The purpose of this paper is two-fold. The first objective to present the key findings collected from experts contributing to the energy efficiency of neighbourhoods. The second is to present a summary of how different areas of ICT can support the improved energy efficiency of neighbourhoods. These objectives form part of the main goal of the IREEN project (ICT Roadmap for Energy Efficient Neighbourhoods). This is to develop strategic research agenda with recommendations for implementation on ways to achieve energy efficient districts.

1.2 *Background*

Information harnessed from earlier roadmaps from the same field has been used to form the foundations to develop an ICT roadmap for energy efficient neighbourhood. These focus primarily on energy efficiency at the building level. Hannus M. et al (2010) developed the first version of ICT supporting energy efficiency roadmap in construction via a European Commission funded project REEB (Roadmap for Energy Efficient Buildings). This work suggested development actions over the short, medium and long term for 1) energy efficient design and production management; 2) intelligent and integrated control; 3) user awareness and decision support; 4) energy management and trading; 5) integration technologies. The REEB roadmap was later updated by the ICT 4 E2B Forum (ICT for Energy Efficient Buildings Forum) project which focused on a European stakeholders' forum. The forum supported crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings (Carosia S. et al 2013). Current trends are towards broader approaches at neighbourhood and even city levels. In this holistic approach, energy efficiency is made up of numerous elements, including buildings and infrastructures, transportation, energy supply, storages and distribution. In addition the involvement of people and the end-users' perspective are identified as a significant element and these elements are addressed in this paper.

2 METHODS

2.1 *Overview of the iterative roadmapping process*

A first task for the IREEN project prior to developing the roadmap was to identify the relevant operation fields. Previous roadmapping work by Hannus M. et al (2010) and Carosia S. et al (2013) identified the key elements of energy efficiency at the district level and hence provided a starting point. From this, the key, focus areas were identified and classified to create the IREEN scoping matrix as presented in Figure 1.

Figure 1. IREEN scoping matrix presenting application and technology areas (Sepponen et al, 2013).

		Application Areas																		
		Neighborhoods - Urban and Rural Communities																		
		Holistic Urban and Rural systems	Transport			Buildings, Infrastructures & Open Spaces					Energy Production & Storage			Energy Distribution			People Involvement			
			Public Transport	Transport Infrastructures	Electric Vehicle Networks	Buildings	Parks, Squares, Greenery and Open Spaces	Public Lightning	Water and Waste Management	Rural infrastructures	Holistic Energy Systems	Electricity Production & Storages	Heating and Cooling Production & Storages	Electricity Systems	District Heating & Cooling Systems	Gas Network	Civic Commitment & Public Participation	Public Information, Education and Training	Privacy and Security	People Behaviour & Consumption Patterns
Technology Areas	**Design, Planning & Realisation**																			
	Design																			
	Modelling																			
	Performance Estimation																			
	Construction and Maintenance Management																			
	Decision Support																			
	Performance Management																			
	Visualisation of Energy Use & Production																			
	Behavioural Change																			
	Energy Management																			
	Intelligent Monitoring and Control																			
	Energy Brokering Systems																			
	Energy Hub																			
	Smart Grids																			
	EE Services: business concepts and financing																			
	Integration Technologies																			
	Process Integration																			
	System Integration & Open Data																			
	Interoperability & Standards																			
	Knowledge Sharing																			
	Virtualisation of the Built Environment																			
	Communication																			

The application fields of the scoping matrix represent energy consumers (buildings, transportation and the entire neighbourhood), energy distribution, production and storage. A category was also allocated to people and their involvement.

In the next phase the aim was to identify and assess the development needs for ICT, considering factors such as: technology maturity, drivers, value chains, partnership, deployment challenges and stakeholder development. This paper includes an overview of key RTD topics for energy efficiency of neighbourhoods, as reported by Sepponen et al, 2013.

Key to the process is the collaboration and communication between stakeholders and end-users of the ICT systems in a neighbourhood. These include residents, buildings owners and users, land and infrastructure owners, designers, operators, energy companies, decision makers and facility managers, to name but a few.

Many experts from different knowledge fields have contributed to the IREEN roadmap via a combination of workshops and interviews. The experts have supported the IREEN consortium through an iterative development process, commenting and developing ideas alongside validation of the work. For example, IREEN consortium partners interviewed 24 city representatives from across expertise fields during early 2013. These interviews were then mapped to the field of ICT and energy efficient neighbourhoods. The interviewees represented urban conurbations, as well as smaller rural towns and districts from across Europe.

2.2 *Key principles of energy efficiency at a neighbourhood level*

IREEN presents a vision for maximised energy efficiency for the entire optimal energy system in a neighbourhood. This requires a holistic approach, including the energy chain and all forms of energy. Accordingly within IREEN, the energy system of a neighbourhood is planned and operated as efficiently as possible in each local surrounding and circumstances.

The key principles for achieving this are: 1) minimisation of energy consumption (enabled with high energy efficiency), 2) energy efficient distribution, and 3) energy efficient energy production and storage.

The intention is that ICT solutions integrate the energy sub-systems of a neighbourhood into a holistically optimised and efficiently operating energy system. From this the entire energy chain of a neighbourhood, from energy consumption to distribution and production are integrated through ICT.

2.3 *Special characteristics of rural areas*

IREEN's vision is relevant for both urban and rural areas. In rural areas the focus is on villages and small towns in adjoining rural and semi-rural areas. Particularly interesting from this point of view is the increase of low carbon and renewable energy solutions, along with decentralized energy production and micro-CHP. Whilst there are overlapping issues between urban and rural systems, the rural context presents unique challenges, as was reported by experts in workshop held in conjunction with the Future of Rural Energy in Europe (FREE) initiative (FREE, 2010).

The IREEN workshops addressed several similar issues in urban and rural areas, such as the need for local approaches, new business and financing models as well as the challenge of behaviour change and raising inhabitants' awareness about energy efficiency. Similarly many buildings are in the need of renovation and people want guidance to selecting the best solutions. It was noted that in rural areas buildings are often less energy efficient than in cities due to age and restrictions (for example, heritage classification).

The unique aspects of rural areas were also identified by IREEN experts. Buildings are often dispersed and connecting them to the surrounding environment is difficult and often not feasible. Related to that, lower densities of population raise mobility challenges. Mobility patterns are also very different in rural areas where the use of individual cars cannot be substituted. This leads to comparatively high transport fuel costs and different energy consumption needs than in urban areas (FREE, 2012). On the positive side, rural areas have good potential for renewable energy production with more physical space available. Rural areas are not only characterised by a large potential for renewable energy production but also by low densities in energy consumption. Potentially rural areas could become energy-independent, eventually supplying urban areas with energy (FREE, 2012). Reliability of supply was also raised as an issue by the experts. The decentralisation of energy systems offer a way forward and the importance of non-grid options in rural areas.

Energy poverty can be more acute for rural households and issues such as lower income levels and energy poverty were raised. Typically people living in rural communities need to be more self-supporting and independent. They can also have stronger sense of individualism and they can be more resistance to change. Other structural challenges include rural depopulation and the increase in the elderly along with a significant seasonal population of tourists and second home owners.

3 RESULTS

3.1 *Communication and collaboration of planning and operation at the neighbourhood level*

Integration and the collaboration of different sectors and expert areas were identified as one of the key aspects for achieving holistic energy efficiency. Traditionally different sectors of municipalities have operated independently. This is typical also for energy, construction and ICT companies. Communication and co-operation between the stakeholder networks is often difficult due to diffused operation and different expertise vocabularies, rendering basics such as a common understanding a challenge in itself. This can lead to sub-optimised decisions, when planning, operation and controlling are not synchronized and may not interact. Information exchange can also be slow and complex.

IREEN aims to identify how ICT can support the overall energy efficiency of neighbourhoods'. This is complex, because it involves a broad network of different stakeholders and organisations. There is a clear need for easier information exchange across traditional operation borders and the improved collaboration of various expertise sectors, and inhabitants of the area already from the start of the planning process. ICT can provide capability to support this. An important aspect is ensuring support for decision makers to understand the different options and their impacts, as well as the added value of ICT investments in relation to the long term and life cycle of the neighbourhood systems. Decision support tools for performance assessment and visualisation of options and their impacts are therefore essential.

3.2 *Priorities for the development of ICT supporting energy efficiency in neighbourhoods*

The aim of IREEN is to identify the priorities for the research and technical development of ICT supporting energy efficiency in different segments of neighbourhoods. A synopsis of main development needs is presented here. These findings are summarised from various inputs from city representative interviews, IREEN expert workshops and partners' expertise.

At a neighbourhood level, integrated city planning and management is the key for transformation towards smart cities. It is important to plan flexible hybrid systems rather than focusing on either small or large scale systems. The retrofitting of existing neighbourhoods is important issue. City representatives expressed enthusiasm for access to and use of 3D models (e.g. for analysing the shading caused from buildings to solar panels), use of Geographic Information System (GIS) for spatial analysis and urban planning, and simplified CO_2 calculations to identify trends. One of the keys to providing a holistic view point is the integration of different experts into the planning process from the initial phase.

Improvements to the energy efficiency of transportation were reviewed from the view point of how to decrease the transportation needs within a district by providing alternatives. These include encouraging people to bicycle or walk. A key issue is the role of the urban planning process as a means to manage and decrease the transportation demand in an area. In the planning phase other traffic solutions need to be considered that can compete with the ease and comfort of private car use. Initiatives such as remote working also have much to contribute. The issue of differing mobility patterns for rural areas was also raised.

Within IREEN buildings are considered from the view point of their interconnections within neighbourhoods and not as single entities (this has been raised in other projects, such as Hannus M. et al (2010)). The development needs for improving the energy efficiency of buildings are many. Retrofit actions and associated efficiencies were raised by numerous city representatives. There is a need for data about the impact of actions. In addition monitoring is essential, both to comparing the real performance in relation to energy targets along with remote monitoring and control of other infrastructures, such as street lighting (for example dimming). Other topics raised were the integration of renewables in buildings and the ability to balance of energy loads.

Related to energy supply and distribution systems, the topic of neighbourhood self-sufficiency and “energy positiveness” was highlighted. This is where an energy efficient district or area uses sustainable energy sources to generate more energy via than is required. This could be achieved for example with increased local and distributed energy production and waste-to-energy utilisation. The example of rural areas was stated earlier. The optimisation of energy systems and remote management at the city level were raised by experts. A key point is the need for energy flows to be visualised to citizens and stakeholders. At a district level energy management, there is need for real time energy data supporting decision making and new energy trading and markets.

People involvement is also essential for energy efficiency. The inclusion of local inhabitants at in the planning phase is crucial. Increasing the awareness of energy usage and possibility for technologies to support people on a day to day basis are part of this. People are genuinely interested in meaningful visualised monitoring that can give them control as well as an ability to see the real time energy use. They want to understand the financial savings of their energy efficiency actions and the amount of local or even their own energy production.

The development of integration technologies were seen as having a pivotal role. A sustainable energy system is a smarter, more unified and integrated energy system (Van der Hoven, 2012). Urban and energy system planning and management tools need interoperability, access to accurate data and the ability to use data. There is a need for information exchange from the many different expertise areas involved and data locations, such as urban plans, Building Information Model (BIM), Geographical Information Systems (GIS), weather and climate conditions, wind and solar conditions, type of terrain, soil and ground water areas, spatial data, transport plans, energy distribution network maps, demographics, energy consumption of buildings and used energy sources, among others. At the same time it is important to not omit governance issues as well as ensuring privacy and security receive careful consideration.

3.3 *Holistic energy management system at the neighbourhood level*

Municipalities are interested in local energy sources, increasing their share of renewable energy, and/or self-sufficiency as well as taking steps towards the energy positive performance of buildings, neighbourhoods and entire cities. However, they have a lack of know-how about how to do this and where to start, especially when access to financing is often limited. Technology can support this by providing guidelines, tools, data sharing platforms and data mining opportunities. ICT can also provide decision support systems, benchmarking tools, performance estimation and the analysis of sustainability impacts (economic, environmental, and social impacts) with easy-to-understand visualisation of analyses and impacts.

The IREEN vision is that the smart energy management of a neighbourhood would enable the optimum energy supply and distribution and balancing of all energy flows. The management of distributed energy systems ,where energy is produced close to where it is being used, needs new types of analysis tools to design and to optimise energy chains extending from generation sites (both large and small scale) to consumption points (IntUBE, 2011). Neighbourhood Energy Management System (NEMS) have the ability to aggregate and control largely autonomously energy supplies along with demand-side resources. In a self-sustainable neighbourhood a well-designed energy supply and management system could potentially provide enough energy to meet the energy demands of the users. This can also support goals, such as reliability of energy supply, carbon emission reduction, the diversification of energy sources and cost reductions.

NEMS take into account the whole neighbourhood offering a significant impact on the future energy systems and the associated control network. It could provide an efficient and economical mean to manage and deliver energy within a neighbourhood in real time. A key goal of NEMS is to maximise economic and environmental benefits to smart energy system users, while also minimising energy distribution losses. Additional savings can be achieved through efficient energy utilisation (management of fluctuating energy production) and higher efficiency of distributed energy production, e.g. through solar, wind and CHP plants. NEMS is therefore able to offer flexible services to the overlay grid, enhancing the possibility to establish new markets and improving the overall efficiency in energy supply.

3.4 *Economic challenges and new potential business opportunities*

Economic issues were frequently raised in the course of the IREEN project. City representatives face a challenge to finance energy efficiency measures and source ICT investments as well as understand the costs and benefits (return of investment - ROI) of solutions. There were inevitable concerns about long pay back times. One of the city representatives interviewed stated that "it is hard to convince people that energy efficiency measures will generate revenues in the future, and pay back investment costs". Hence the need for new business and financing models.

The need for new business models for operation processes was also raised. One of the future scenarios developed during the project was that of an energy broker, who would sell and buy energy on behalf of its customers. These would be energy consumers, prosumers (an energy consumer who also produces energy) and distributed energy producers. The energy broker balances the energy supply and demand in the neighbourhood in real time. Some of the distributed energy production would be from fluctuating energy sources, such as solar and wind energy. The broker has several means for balancing, such as demand side management (as agreed with customers), control of non-fluctuating energy production sources (from renewable energy sources), and local energy storage (including electric vehicles). The energy broker model is illustrated in Figure 1 and concept is presented in a more detailed level in the IREEN document by Cricchio F. et al (2013).

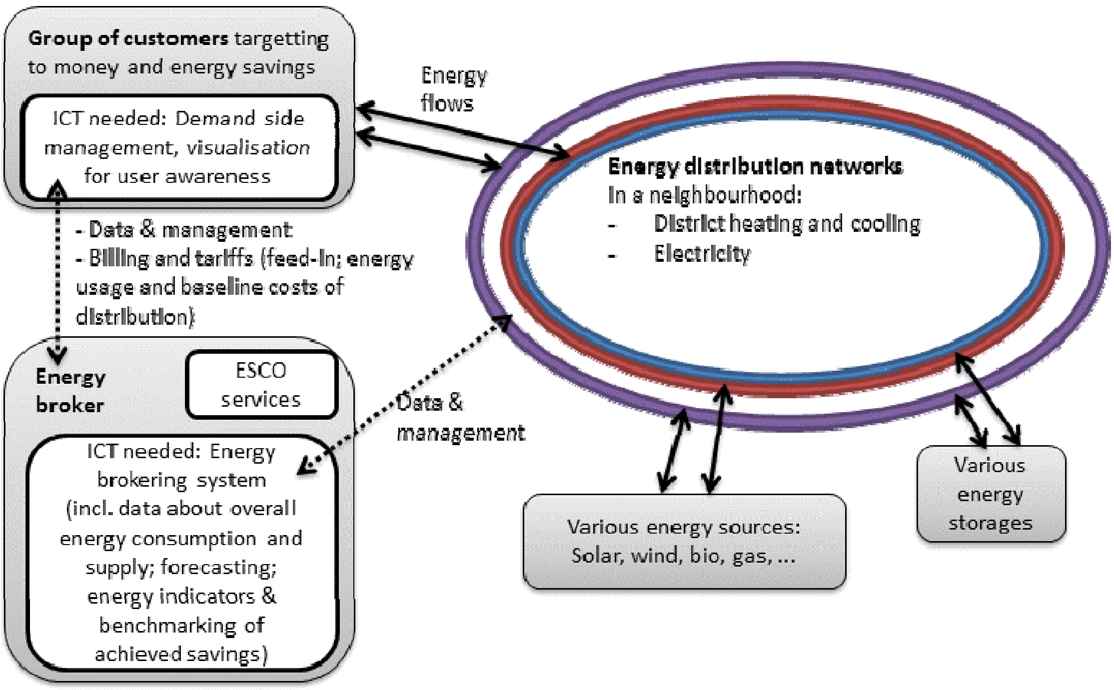

Figure 1. Illustration of the operational network from the energy broker scenario Cricchio F. et al (2013).

3.5 *Highlights of the development needs from the rural energy view point*

Experts contributing to IREEN have stated that the ICT solutions supporting urban and rural communities are similar and hence separation is not necessarily required. Despite the fact that the physical solutions in rural areas are clearly different than the ones in urban areas, when it comes to ICT solutions, such as control systems, there are few differences. Transportation and associated systems present the biggest variance between the development needs of urban and rural areas. Rural areas have lower densities of population and it is more challenging to increase the energy efficiency of transportation by means of neighbourhood planning (as in urban areas). The profitability of public transportation is also challenging. Longer distances between buildings make it difficult to connect their energy systems into the surrounding neighbourhood and questionable if it is worthwhile. On the other hand, rural areas offer a large potential for renewable and distributed energy production due to the availability of physical space and geographical terrain, for example elevations suitable for wind power.

One of the technology benefits identified by the IREEN for rural areas is technologies shortening distances and hence the importance of good broadband connectivity. ICT need broadband and many rural areas are not well served. ICT can also play an important role in smart funding models, such as crowd funding.

4 CONCLUSION AND DISCUSSION

The IREEN vision is that the smart energy management of a neighbourhood enables optimum energy distribution and balancing of all energy flows, resulting in maximised economic and environmental benefits. The majority of cities have a large amount of existing infrastructure i.e. buildings and in some cases entire neighbourhoods which require renovation and modernisation in the not too distant future. Therefore the development needs of ICT supported district level energy efficiency focus on two distinct levels in the initial steps towards smarter cities: firstly the development of entirely new areas. Secondly the renovation/upgrading/modernisation of existing neighbourhoods, Many municipalities are also interested in local energy sources, increasing their share of renewable energy supply, and/or self-sufficiency and in some cases, energy positive performance of buildings, neighbourhoods and even entire cities. However there is often a lack of know-how on how to realise these ambitions.

IREEN aims to identify how ICT can support the overall energy efficiency of neighbourhoods. This is relatively complex due to the broad range of stakeholders and organisations involved. The integration and collaboration of different sectors and expert areas has been identified as one of the key aspects of achieving holistic energy efficiency at a neighbourhood level. Traditionally the different sectors of municipalities have operated relatively independently, as is often the case for energy, construction and ICT companies. This can lead to sub-optimised decisions, when planning, operation and controlling are not synchronised and in some cases not be connected. Alongside this information exchange can be inefficient.

There is a clear need for easier information exchange over traditional operational borders and for improved collaboration by the expertise sectors. This should include the inhabitants of the area at the onset of the planning process. ICT can provide the capability to support this. It can also support municipalities in the challenges related to improving energy efficiency by providing guidelines, tools, data sharing platforms and data mining.

An important aspect is to provide support for decision makers for analysis of different options and understanding their impacts, as well as help to comprehend the added value of ICT investments over the long term and life cycle of the neighbourhood. Here decision support tools play a crucial role for performance assessment, benchmarking and easy-to-understand visualisation of sustainability impacts (economic, environmental, and social impacts).

Integration technologies are an important area for ICT for energy efficient neighbourhoods. Open communication, ease of access to and utilisation of a range of data sources is a priority development topic. The synergies between different expertise fields need to be taken into account. The creation of truly energy efficient (or even net energy or energy positive neighbourhoods) requires effective collaboration, participation and knowledge exchange between stakeholders from the different expertise fields. For example, the stakeholder network needs to include urban, district and neighbourhood planners, transport system designers, energy companies and designers, ICT experts, and local people living and/or working in the area. In addition, governance issues, namely privacy and security should be borne in mind.

The project has focused on both urban and rural communities and the challenges they face to create energy efficient environments. In many ways ICT for both urban and rural communities are similar. Transport is significantly different between urban and rural areas due to the dispersed infrastructures and population. As a result is it challenging to improve the energy efficiency by transport planning in rural areas. However rural areas do offer a greater potential for renewable and distributed energy supply.

A clear message from the city representatives has been that RTD and the innovation of ICT itself is not enough, and that emphasis should also be given to economic related challenges and ROI, as well as ways to access financial support. These present opportunities for new business models. Another important aspect is the need to increase the energy efficiency awareness of end users, urban planners and other designer, and create citizens opportunities to take part in the planning process.

The findings presented in this paper form the basis for the development of the IREEN roadmap (a strategic research agenda) for ICT supporting energy efficient neigbhourhood over the short, medium and long term. This will be followed by tangible implementation recommendations for each stakeholder group with a role in realising district level energy efficiency and the upgrading of the built environment towards smart city aspirations. The IREEN roadmap aims to support future research needs and actions, as well as providing implementation recommendations, targets and ideas for a range of stakeholders.

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Monitoring and evaluation of urban regeneration processes. The case of Cova da Moura.

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ABSTRACT: In urban planning, monitoring and evaluation are increasingly becoming mandatory by both national governments and international organizations. These instruments aim at verifying the degree of coincidence between results and objectives proposed and to ensure the correct use of resources. It reflects the demand for new forms of public policies legitimacy and, in more ambitious perspectives, seeks to promote the deepening of democracy.
This paper focuses on the case of Cova da Moura, a settlement that resulted from occupation of private and public land and chosen as a pilot neighbourhood by the public policy named Iniciativa Bairros Críticos (IBC) (Law 143/2005). The IBC defined an innovative qualifying urban agenda fomenting public participation and including monitoring and evaluation. However, the difficulty of negotiation and shared decision-making process resulted in the bureaucratization of practices, prevailing the technicist visions towards a top-down driven process. This research is part of a broader, multidisciplinary project (named 'Exploring the contributions of relational space for promoting the right to the city. Experimental research at Cova da Moura, Greater Lisbon ' developed by the Grupo de Estudos Socio-Territoriais, Urbanos e de Acção Local | CIAUD | FAUTL) which explores the contributions of a collaboration between architecture and anthropology in urban intervention. Monitoring and evaluation are understood here as instruments for collective and participatory analysis of processes. Based on comprehensive and action-oriented methodologies, rather than an approach targeted to 'accountability', it aims to understand and learn from the ebbs and flows of processes involving multiple stakeholders.

1 INTRODUCTION

This work emerges from the collaboration with the multidisciplinary collective Study Group named *Grupo de Estudos Socio-Territoriais, Urbanos e de Acção Local* (Gestual) integrated in the Centre Research in Architecture, Urbanism and Design, of the Faculty of Architecture of the Technical University of Lisbon. Gestual focuses on applied research, on the close interaction between researchers and local communities, in order to build bridges between academia and social movements in semi-urbanized or self-produced areas. It is also the result of a personal research, under a PhD in urban planning, in progress on the Faculty of Architecture of the Technical University of Lisbon, named "Participated urban qualification programs of self-constructed neighbourhoods. The space outcomes and the contribution of monitoring and evaluation."

This text focuses on the project that is being developed by some members of Gestual, funded by the Fundação para a Ciência e a Tecnologia, named 'Exploring the contributions of relational space for Promoting the right to the city. Experimental research at Cova da Moura, Greater Lisbon ' (ERDC project). The aim is to present an intercalary evaluation of the actions taken so far in the neighborhood of Cova da Moura, identifying progress and setbacks, obstacles and opportunities for achieving the goals initially set. This text is assumed as a reflective moment on the actions taken by the ERDC project without disregarding the work of collaboration developed between Gestual and the local associations of Cova da Moura, for several years, under the agenda of urban qualification.

The text is organized into three points: (1) Monitoring and evaluation of urban regeneration processes; (2) The qualification urban process of Cova da Moura; and (3) Project ‘Relational Space and the Right to the City’: Intercalary Evaluation.

2 MONITORING AND EVALUATION OF URBAN REGENERATION PROCESSES

The urban interventions programs in self-produced urban areas present difficulties in the design of solutions and their implementation. These modalities of intervention usually result in time-consuming processes, unable to incorporate unforeseen opportunities and local dynamics, although we watch the emergence of innovative interventions that include participatory and negotiated methodologies. In urban planning, public participation, monitoring and evaluation are increasingly becoming mandatory by both national governments and international organizations. It reflects the demand for new forms of public policies legitimacy and, in more ambitious perspectives, seeks to promote the deepening of democracy.

Some innovative programs rely on plans provided by Law and European directives, witch includes monitoring and evaluation mechanisms as well as participation. These are some of the requirements for the support of EU funds that aims to guarantee, in line with what some call the communicative planning (Khakee 2008), the continuous observation of modes of communication, of debates and political agenda, to gather both the quality of the planning process and program activities, through the development of collaborative processes and learning from the broad participation of stakeholders (Healey, 2003). Nevertheless, recent examples show that the new instruments of urban planning have not yet succeeded to break with the dirigiste tradition of the modern period (Bourdin, 2011) and the decision-making tends to be on the side of technical knowledge and oriented by top-down processes, prevailing the rationalist/functionalist paradigms.

Different approaches emerge thought based on an interactionist paradigm (Raposo, 2012) and on practices of monitoring and evaluation of plans (CESUR, coord. Silva, 2007; Indovina & Ferreira, 1999) witch rescue the concept of reflexivity (Giddens, 1987; Ascher 2001) to achieve more sustainable results. These approaches hold on the interaction between research and project, on bottom-up practices and on the importance given to the process as a resource to incorporate on solutions unforeseen opportunities or agreements (Portas 2005).

Consistent with approaches that advocate greater flexibility of the regulatory instruments implying more reflective attitudes we aim to reflect on ways of making city and realize to what extent they operate in favour of the right to the city as the right to transform ourselves whilst transforming our space (Lefebvre 2009, Harvey 2008).

3 THE QUALIFICATION URBAN PROCESS OF COVA DA MOURA

The neighbourhood of Cova da Moura, located at the doorstep of Lisbon (at the municipality of Amadora), results from the progressive occupation, since the 1950s, of public and private lands. Like other self-produced urban areas that arise at the time in the Lisbon Metropolitan Area, the occupation of the land of Cova da Moura stems from a housing need, which found no response in national housing policies or in the private sector. Its population is linked to the migration movements from the interior of the country and from the former colonies of Africa The occupation of the land of Cova da Moura has two distinct phases: at first, the occupation of the territory assumes a regular pattern (1960s and 1970s); later, the densification of urban fabric results on a lost of original readability affecting the living conditions.

During the post-revolutionary (post 1974) period characterized by political and social changes, the strong social mobilization for housing and place rights was supported by of the city council - at the time, the City Council of Oeiras, and later in 1979 by a restructuring of administrative boundaries, the City Council of Amadora - by the construction of infrastructure and the creation of an office for technical local support.

More recently, in the neoliberal context, the way public institutions perceived these urban areas as changed. Although interested in integrating these neighbourhoods in the formal city the public institutions procedures are characterized by burocratization and technicization and focus on the fulfilment of legal parameters in the processes of regularization.

In 2002, is presented by the City Council of Amadora (CMA) a Detailed Plan proposing the demolition of about 80% of the neighbourhood, declining mostly the typical buildings from the expansion of cape-verdian cities, where most of inhabitants came from. The plan caused reactions among the population and local organizations, which joined forces in setting up a Neighbourhood Comission (NC) and rised up against this solution. It was the impact of social movements, along with the studies of a group of students from the Faculty of Architecture - UTL for an alternative plan, in 2004 that captivate the attention of the central government and the media. In 2005, is created the Critical Bairros Initiative (CBI) (Resolution of the Council of Ministers 143/2005, of September 7th) and Cova da Moura is selected as one of three experimental neighbourhoods. The initiative proposed innovative principles oriented to the qualification of the neighbourhood, as well as to participation and partnerships between six public ministries, local actors (CMA, NC, and other partners) and technical support (Raposo, 2009). The process, coordinated by the central government (by the National Housing Institute, now Urban Rehabilitation and Housing Institute (URHI)) varies, however, between a first period very interactive and shared that draws the diagnosis and action plan (between January and November 2006) and a final period characterized by the CMA leaderships of the process, thought still under the supervision of URHI, in witch depended two main actions for the neighbourhood qualification: the land legalization and the drawing of a detailed plan (Raposo & Jorge, 2013). Numerous conflicts between NC and CMA followed a period of bureaucratization of participation, and the first proposals for a detailed plan were the expression of a technicist vision concerned strictly with hygienist issues and legal parameters. In April 2012, the URHI (from the central government) abandons the process induced by a period of economic crisis and the need for public spending cuts. Since then the design of the detailed plan is suspended, depending exclusively on the action of CMA, who has remained unreachable despites the NC attempts of contact, making predict that the current crisis and the lack of financial resources compromise the conclusion of a detailed plan.

The Neighbourhood Commission is now entering a new phase of action, seeking influential allies (in academic and professional fields) that may contribute to solve the problems on the qualification agenda, particularly in what concerns the tenure legalization, the drawing of an alternative qualification plan and small urban improvements to avoid a degradation process of the neighbourhood. The Faculty of Architecture is one of those allies, represented by Gestual, who has been providing technical support to the NC since 2004, during the CBI and know on co-designing an alternative detailed plan.

4 THE PROJECT ‘RELATIONAL SPACE AND THE RIGHT TO THE CITY’: INTERCALARY EVALUATION

The ERDC Project is a short-term (12 months) exploratory research outlined with the intention of “contributing to a better understanding of the nature and transformative potential of the Lefebvrean notion of The Right to the City, as it germinates in the context of actions by people and institutions on the ground, willing to engage themselves in the definition of how their urban place is shaped. In particular, the research looks at and experiments with new forms of articulating academic knowledge with initiatives by other social actors in order to fill the gap between largely abstract insights regarding the right to transform ourselves while transforming our space and the concrete actions undertaken in particular territories.” (Carolino et al., 2012)

Two core purposes are defined by the project:

. to look at the potential of a relational conception of space and of multidisciplinary collaboration for the formulation of alternatives to the conceptions of space, place and social process that inform neoliberal policies (and conceptions associated);

.to indicate concrete paths for basing qualification proposals on space as it is experienced and appropriated as a resource by the inhabitants (dwellers).

At this point, there are three ongoing tasks in the project. Task 1 (local laboratory), task 3 (workshops with the inhabitants) and task 4 (ehtnographic and typo-morphological analysis). Task 2 was concluded (opening seminar). Task 5 has not yet started.
To what concerns to monitoring and evaluation we choose here to take special attention to the design project circumstances and to task 1 and 3 in order to situate the crucial difficulties of the ERDC project.

The project proposes the co-construction of parameters and tools for evaluation and monitoring activities that draw on themes and idioms meaningful for those involved.
The monitoring and evaluation activity has been developed, until now, with distinct resources in two different moments: i) concerning Task 2 (opening seminar, concluded) it was possible to define along with the NC a participatory monitoring an evaluation (PM&E) process. Three different meetings where made with the NC to define the objectives and the logistic of the seminar. When concluded, it was promoted an evaluation meeting among the team members and another between the team and NC; ii) concerning the task 3 the team is still thinking how to engage inhabitants and NC to co-construct (team/NC/inhabitants) a monitoring and evaluation tool; the monitoring and evaluation as been made, until know, with the teams members.

4.1 *The Projects design: articulation between academic knowledge and social movements?*

The ERDC project was formulated following a dialogue established between Gestual e Cova da Moura's organizations over the last years. It results, furthermore, from the articulation of the individual doctoral and post-doctoral researches carried out by team members, which include two shared concerns: an experiment of innovative modes of relation between the university and social movements; and to relate abstract notions of the Right to the City with the concrete struggles of social movements on the ground.

The project aims to establish a dialogue with the 'qualification agenda' as it is defined by its actors, having in mind the current impasse (following the interruption of the Critical Bairros Initiative) and the new paths of action that the NC has been envisaging for qualification. One of the orientations identified by the NC regards the importance of promoting small improvements in the neighbourhood, aiming at both showing to 'the outside' that Cova da Moura remains active in spite of the public institutions withdrawal of the qualification process; and preventing a further degradation of the physical condition of the neighbourhood – at stake are interventions at the level of the blocks and public space.

The dialogue and collaboration between NB and Gestual proved to be pertinent and desired in this new phase of the qualification process (post-CBI). This was explicitly formulated in two distinct moments, which turned out to be central for the start of the ERDC project:

i) in November 2012, at the first NC meeting for the planning of the seminar *Cova da Moura, que desígnio, que desenho. A qualificação sócio-espacial - balanço e perspectivas* (witch was also the opening seminar of task 2 of the ERDC project), which was desired as a moment for making an appraisal of the *Critical Bairros Initiative*, to make inhabitants of Cova da Moura aware of the current situation of the qualification agenda and, simultaneously, to launch the basis for the creation of a group of experts/technicians/consultants mobilized for the discussion of future action regarding Cova da Moura's qualification.

ii) the application to 'Apoio Pontual DGArtes 2013', formally undertaken by an informal group engaging both Gestual and the NB (*Colectivo ao Largo*), with a proposal named *Este Largo Podia ser Assim* (This square could be like this). The application set forth to "undertake a qualifying intervention at the public space of Cova da Moura, having at its core a square with acknowledged potential for the fruition of urban life" (Grupo Informal 'Colectivo ao Largo, 2013). However, the proposal was not financed.

The open support by NB to the actions mentioned above was however not extended to the ERDC project. Although the dialogue with the NB played an important role in the structure of the project, the project itself was discussed only with Moinho da Juventude (MJ), due both to lack of time and to the greater understanding and proximity between the project coordinator and that organization that resulted from one year of work and cooperation in other projects (June 2011 - May 2012). The ERDC project was partially rejected by the *Associação de Moradores* (AM) and the *Associação de Solidariedade Social do Alto da Cova da Moura* (ASSACM), due to the project's scholarly outline and the fact that its main purpose was not the construction of a material proposal. The local organizations expressed the view, also considered by the project's team, that the inhabitants of Cova da Moura were not keen to welcome further enquiries by students and researchers that would not entail any material outcome for the neighbourhood and people's lives. Even after the dimension of physical construction was added to the project, the support of the two other organizations (AMBACM and ASSACM) has not been expressed, neither have the organizations felt the process as theirs.

The dynamics of relation with the three local organizations and its impact for the project's aims seems to have not yet been discussed enough by the team. However, it was discussed by the team that it was important to take distance from the 'tripartite logic' of the NB (which was found and conditioning during the preparation of the opening seminar – task 2) and that the project would find legitimacy, instead, through and engagement with the inhabitants directly. In this sense, other options were also made: to not negotiate/define with the organizations the concrete places in which the workshops would take place and to not engage them closely in the planning of the activities.

These choices vis-a-vis the NB are not yet stabilized by the team, since they interfere with some of the specific purposes of the project's tasks: to launch a laboratory (task 1), involving the permanency of the team at Cova da Moura. It was foreseen that a physical space would be provided by the organizations which would enable the team to ground its activities on the bairro's daily life, the gathering of data and the contribution of the project for formulating proposals of transformation that would be based on an approach to space as the outcome of human relations and on the notions and practices of the people most affected by the qualification process (task 3: workshops).

4.2 *The ERDC project's tasks*

Differently from the plan established for Task 3 (the workshops) the team has currently interrupted some of the activities being developed at Cova da Moura, due to a need for team reflection regarding strategies followed and methodologies. At stake are the discussion of concepts and their appropriation by the different academic disciplines, as well as the construction of a frame of reference for monitoring and evaluation the project's realization.

4.2.1 *Task 1 - Local laboratory (ongoing)*

Objectives: This task launches and maintains a local laboratory with the purpose of diminishing the distance between the research team and the daily life of Cova da Moura and enabling the team to ground the activities planned on the local conditions and perspectives. The laboratory situates and sets in relation the different activities planned in the course of the project (tasks 2 to 5) and interrogates their development according to criteria for evaluation that operate with the notion of the right to the city.

Task 1 is up to now partially conditioned by the lack of engagement of the NC as a group, in the process. Although the organizations have offered their facilities for use of the team, this was made with no manifest engagement (with the exception of MJ). The team has not insisted on fostering that engagement at that moment; instead it opted for building that relation as the project unfolded with the inhabitants. More recently, the team used twice the facilities of MJ, as required by events in course. Contacts were also made with ASSACM for information and invitation for the planned workshops.

This question is currently under discussion within the team, insofar as a need is felt to *shorten the distance between the research team and the daily life at Cova da Moura, as well as enabling the team to plan the activities in alignment with the local conditions and perspectives.* Proximity has been concretized on a near-daily basis by one of the team members. Although the changes identified in task 1 meant that the workshops (task3) have gained a more crucial role as a mean for engaging inhabitants, it is felt by some members of the team that a greater permanency at the spot (with or without a working space there [facilities]) would allow for deeper knowledge of the *largo*'s daily life as part of a wider urban setting, as well as of the people that inhabit it and inter-relate there.

Regarding task 1, the co-construction (team/NC/inhabitants) of a tool for monitoring and evaluation is still missing. A proposal that may concretize a negotiation of this tool is currently being seen by the coordination as key for the greater engagement of inhabitants and the local organizations.

4.2.2 *Task 3 - The workshops (ongoing)*

Objectives: This task comprises the planning and undertaking of public workshops entailing a reflection about the socio-spatial characteristic of the bairro and potential transformations. The purpose of this task is to learn about how the inhabitants perceive and relate to each other in a given area. On the other hand, focusing on the dynamics of appropriation that characterize the socio-spatial shaping of the bairro, it dialogues directly with the key issues of the qualification agenda (such as space legibility, lack of public/green space, conditions of habitation) through an attention to what inhabitants do (rather than what lacks in the bairro). This task constitutes both an opportunity for data collecting and a specific contribution of the project for creating the conditions that allow local organizations (the Local Commission) to articulate proposals in line with the relational character of space and the conceptions and practices of those more affected by the qualification process (space 'users', especially the inhabitants and house owners).

To what concerns to task 3, the team decided to concentrate the 3 workshops at a location in which the team had already started a process – the *Largo*. This option is considered to have become a structuring choice in the project. It renders less evident the purpose of a morpho-typological analysis as an inductive path for interpretation and proposal. It is also considered, however, that the question regards theoretical-methodological approaches, rather than the location chosen. It is currently under discussion whether the team should consider making subsequent workshops in other areas of the neighbourhood.

Task 3 led to important methodological interrogations and discussions within the team, especially but not exclusively after the accomplishment of workshop 1 (on the 29th June 2013).

The project coordination considered that the workshop operated with the notion of absolute space/space as a container (witch is associated with neoliberalism and at the source of social exclusion), thus undermining the possibility of accessing comprehension with recourse to an approach to space as relational and a social resource (in the sense proposed by Lefébvre e by Harvey in the right to the city). She argued that the use of finished models, used in the session with adults, elicit data about what to place 'inside' the *largo (what is missing in the neihgbourhood),* thus operating the notion of space as a container. Differently from this, a tool was needed that would allow to ask (that the team asks itself) 'what is the *largo*'(including what the inhabitants do). This option is important in the project and was planned methodologically through the construction of a material representation of that place at stake (through a model) by the inhabitants – the idea was that by constructing together a representation of the place people would express notions, concerns, connections, separations, etc that would provide access (clues) to the meanings of place. These clues would be followed through interviews, starting with the idioms (themes, used words…) that were found in content analysis of the workshops (thus the importance of video recording).

The construction of a model with the inhabitants was discussed in the preparation of the workshop. It was considered by the workshop team not viable because it could not be accomplished within two hours (time estimated for the workshop). The construction of the model would only be possible if there was a laboratory, as established in task 1, which would enable the construction during a longer period, for instance with children. The choices made for workshop 1 were also an outcome of the unexpected reaction of some inhabitants in face of team presence (at a video display on the 14th of June) and the purpose of bringing transformation to the Largo. The preference for 'doing nothing', expressed by some residents, and the importance given to parking (the predominant current function of the largo) took the workshop-team to choose a session focused on reasons to keep or transform the largo and on the potential of functions that may co-exist with parking (following the 'opening' that followed new references offered at the Display). These options aimed at not ignoring what people were saying. To move forward to the planned activities seemed not to make sense at that moment. However, the preparation of the workshop required more time for reflection in order to articulate what people said with the actions planned in the project and the reflection about the consequences of choosing some tools for action rather than others. The limited number of team members in face of the project's ambitions was also indicated as a meaningful limitation for several times.

The strategy used for workshop 1 ended up resulting in a more complete version of the first event ('*Este Largo podia ser assim*" in June 2012). The accent was maintained in what people want for that space and communication proceeded through individual or small-group conversations. Other elements were introduced (a model 1:100, the ideas previously collected), but it remained a conversation-based collection of opinions about what to do at the *Largo*.

Having in mind the workshops' aims, a reflection was undertaken, with residents, regarding *potential transformations*. However, an understanding of *how the inhabitants perceive and relate to each other in a given area,* was not yet achieved. On the other hand, a greater involvement of the NC in the workshops is lacking, and the conditions were not created that would allow to contribute for the articulation by *local organizations of transformation proposals based on an understanding of space as an outcome of human relations and on the conceptions and practices of those who are more affected by the process of qualification ('space users', especially inhabitants e house owners).*

It should be said that more people attended to workshop 1 than to the display event, namely the people who live at the Largo. It was important to keep the strategy of door-to-door invitation. Individual contact allows to explain the purposes of workshops and keep contact with people outside the days of events. This contact reinforces the relationships between team and inhabitants. People start knowing the team, however the predominance of children and women is noted, with men placing themselves at the limits of the largo (café, balconies, doors) and not interacting.

5 CONCLUSIONS

The progress of the ERDC project allows the team to understand that the research time and the practice time don't work hand-by-hand, taking into account that an interaction process depends on non-controlled and unpredicted dynamics, interests and power relationships. The confrontation to social practices led the team to take non-predicted choices in order to include the inhabitants concerns and to engage the three local associations at the same level (even if it was not achieved yet). Seeing the process as an important resource and part of the solutions, the team is at the moment in search for the adequate methodologies to proceed with the aims of the project.

Based on a reflective attitude, the team is constantly between research and project, theory and practice (for instance, the questioning about the finished models meanings to achieved the aims of the research project) to indicate concrete paths for basing qualification proposals on space as it is experienced and appropriated as a resource by the inhabitants. A more focused methodology on relational space is needed in the next workshops so it would be possible to better understand how abstract concepts as the right to the city, as the right to transform ourselves whilst transforming our space, is perceived on concrete struggles of social movements on the ground.

One of the main challenges, by this time, is to find a monitoring and evaluation tool capable of engaging inhabitants and local association without becoming too analytical and uninteresting for them. One of the ideas is to use social design tools and co-construct a storyboard of ERDC project process. The aim is to find an on-going tool that could be constantly appropriate and, if needed, transformed by people so both the team and the inhabitants could understand the different stages of the process.

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How to address sustainability at the city level

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ABSTRACT: A brief analysis of the environmental, social and economic paradigm of nowadays cities, allows reaching a conclusion: current cities are not sustainable. Considering this, it is very important to study the causes of such unsustainability and to develop models for sustainable cities. There are a limited number of studies in this area, but the scientific community lacks even more studies related to the implementation of these models in current cities. Consequently there is the need to explore this field. This work emerges with the objective of analysing how it is possible to implement sustainability in cities throw the development of a sustainable city model and an urban regeneration plan. The development of sustainable city models is a very complex topic. The analysis of the state of the art shows that one must consider the relation between environmental and social aspects in the development of sustainable cities, while taking special concerns when considering the economic issues. It was also concluded that cities should be subject to performance assessments. It was also demonstrated that a city can only be sustainable if its population behaves in harmony with the city's sustainability model and that the behavior of a community is determinant in the sustainability level that a model can achieve.

1 INTRODUCTION

Our planet has been suffering profound changes in the last 60 years. Due to these changes, the world faces serious problems in the beginning of XXI Century at environmental, social and economic levels. These problems are caused mainly by the conjugation of three main factors: population growth, excessive resources consumption and increase in pollution (on air, water and earth). The construction sector is one of the major responsible for these negative impacts on the planet, being responsible for the extraction of about 24% of raw materials and the consumption of almost 40% of energy in Europe (EC, 2011), producing 35% of gases contributing to global warming (EU, 2010). The sector also produces 22% of all residues in Europe (APA, 2012) and 40% at a global scale (UNEP, 2011). These environmental impacts combined with the high importance at the social and economic levels show that the construction sector is not sustainable. This fact is even more notorious shifting from the building scale to the city scale.

In fact, it is common the recognition that nowadays cities are unsustainable. The World Wildlife Fund, in collaboration with the Global Footprint Network indicates the concept of environmental footprint as an indicator suitable for quantitatively access the level of sustainability of the planet and also the cities. In this report, the ecological footprint of Europe is 4.72. This means that if the entire planet would follow the lifestyle of the European inhabitants, 4.72 planets would be needed to meet the needs of the world population. The global average is in 2.7 planets, clearly showing that current state is unsustainable (World Wildlife Fund, 2012).

Over the past two decades, the appliance of the concept of sustainable development to the construction sector has been considered as one solution to solve these problems, emerging the concept of sustainable construction. Aiming to contribute to the implementation of this concept, sustainability assessment methodologies have emerged. BREEAM (Building Research Establishment Environmental Assessment Method) was the first environmental assessment method for buildings and was developed in the UK by researchers from BRE (Building Research Establishment) in 1988. This methodology has undergone many changes since its launch and in recent years has developed BREEAM International, which allows the use of this methodology internationally (BRE, 2013).

Another methodology for sustainability assessment with great impact at the international level is the American LEED (Leadership in Energy and Environmental Design) which was established in 1996 and is managed by the U.S. Green Building Council (USGBC). The expansion of this system to the outside of the United States is notorious, being used in many countries worldwide (US Green Building Council, 2013). Also in 1996, there were two important assessment methodologies sustainability, the SBtool (Sustainable Building Tool) and HQE (Haute Qualité Environnementale). The SBtool initially called GBTool (Green Building Tool) is a system developed by a team of stakeholders from more than 20 countries. This Green Building Chalenge tool (GBC) was promoted by the International Initiative for a Sustainable Built Environment (iiSBE) and aimed to the creation of a system adaptable to the constraints of a local or regional building (Larsson, 2012).

In 2013, there are already dozens of tools available on the market for assessing sustainability in construction, mainly adaptations of the methodology SBTool. For example, in Portugal SBTool PT was developed, SBTool CZ in the Czech Republic; Protocol ITACA in Italy and SBTool Green in Spain. These methodologies are recognized as a way to enhance the application of the concept of sustainable construction, improving the performance of buildings and setting good practices that minimize the environmental impact of buildings.

However, some researchers are skeptical of some concepts used in these tools. The main criticisms are related to the efficiency of these methods in the assessment of sustainability and its effectiveness in improving the built environment (Senbel et al., 2003) (Bendewald and Zhai, 2013). One of the issues is based on the fact that these methods do not take into account the relationship between the buildings and the carrying capacity of the environment, since the buildings sustainability assessment is performed by comparing one buildings performance with benchmarks. Common construction practices benchmark is normally defined as existing and old buildings (low performance) and this may result in the assignment of sustainability levels that are not in line with reality. This is because new buildings are normally slightly better than conventional buildings, providing always high performance levels when compared to these benchmarks. It is common in sustainability assessments the attribution of ratings A and A+ to buildings. Nevertheless these buildings may be unsustainable when compared to the carrying capacity of the environment in which they operate.

Another common criticism is that these methods only assess the buildings when they should evaluate the entire set of buildings and infrastructure in a global scale with a holistic view. In fact, a building does not function as an isolated element but as an element that interacts with the environment in which it operates. Thus, the sustainability of the construction sector should be thought not only at the building but also at the urban scale. The scientific community is beginning to absorb this idea and there are some emerging studies that argue that sustainability should be considered at the city level (Bragança et al., 2013).

Taking this into account, recent initiatives have emerged to assess sustainability in urban planning. In 2008 BRE launched BREEAM Communities (BRE, 2012) for the evaluation of small enterprises and urban settlements. This methodology has already been updated in 2012. In 2009 LEED for neighborhood was launched (USGBC, 2012). iiSBE International convened a working group composed of urban technicians from various countries (Urban assessment working group) and is also developing a tool for the same purpose, SCTool (Sustainable Communities Tool) (iiSBE, 2013).

However, there is still some uncertainty in the criteria that these methodologies should access and that an urban area or city should verify to be considered sustainable, since most tools are still under development. Nevertheless, there are some studies that define sustainability criteria that cities or communities should satisfy, but there is still much work to do in the design of sustainable cities. Considering this important research gap in the area of urban sustainability, this work comes up with the objective of analyzing the processes and stages needed to transform existing cities into sustainable cities. The research question of this work is: How is it possible to transform existing cities into sustainable cities?

2 INSIGHTS FROM THE STATE OF THE ART

2.1 *Sustainability in nowadays cities*

With a growing world population and its continuous migration to cities, the needs of modern cities for energy, food, water and other materials have increased dramatically and are suppressed almost exclusively through importation, usually at great distances. This growing dependency of goods across borders puts the environment and life support systems on earth at risk (Grimm et al., 2008). In fact, the culture of import and export fostered by globalization and the current consumerism model completely neglects the environment and is unfavorable to society. The increasing dependence of urban societies in foreign goods causes a decrease in local production capacity and consequently causes social and economic dependency. The loss of local power in cities and countries allows the well- being of the communities to be placed in the hands of a small number of companies and people who often have no understanding or respect for the local economy, the community and their cultural and environmental interests (Grewal and Grewal, 2012a).

The companies linked to the construction sector are an example of this problem, because they have no economic incentive in the consideration of environmental and social aspects in their business (Grewal and Grewal, 2012b). Taking this into account, there is the promotion of an excessive consumerism in favor of the economic performance of companies (Roseland, 2005), resulting in an unsustainabe built environment, especially at environmental level (Rosales, 2011). The large volume of construction in the last 30 years was economically advantageous for construction companies, especially those that were linked to public works. However, due to excessive construction, a housing bubble triggered the 2008 economic crisis. In fact, Eurostat data (Figure 1) shows that in Europe 27, the construction sector had a continuous and uninterrupted growth until 2008 (Stawińska, 2010).

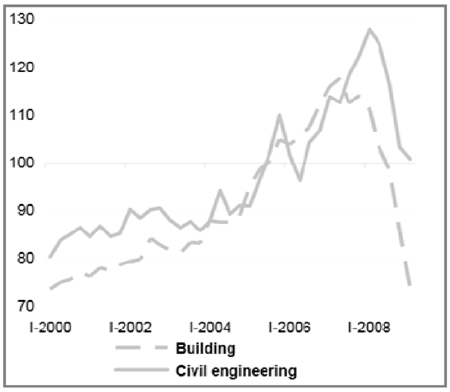

Figure 1. New construction in Europe 27 (EU-27) separated by building and engineering works (2005=100%).

For example, according to the results of the Portuguese 2011 census, the city of Braga, with 125.000 inhabitants, has an oversupply of about 19.000 dwellings (70.000 houses) in relation to the number of families (51.000 families). In Portugal there are more 45% of households than families (INE, 2012). This shows that housing was not increased in line with population growth that occurred in the city, countering the theoretical principles of the law of supply and demand. Amado states that in Portugal, the boom of urban expansion was regulated by insufficient and inadequate legislative principles, which led to a territorial organization without rules and planning (Amado and Ribeiro, 2011).

Regarding the serious problem of overbuilding, there is also a set of problems related to the way of life of urban populations that make cities sustainable. Taking into account the present economic model of consumerism in today's society, there is a huge consumption of materials and products that result in the excessive extraction of raw materials and waste production, when compared to values of non-urban populations.

Air pollution and noise in urban areas are also factors that degrade the life quality in cities. These problems are often aggravated by imbalanced urban development and increased mobility and traffic. As a consequence, the amount of emissions and noise due to road traffic has been pointed out as the main reasons for non-compliance with regulations concerning these matters (Silva and Mendes, 2012).

2.2 *Criteria for the development of sustainable cities*

Considering these problems in current cities, it is imperative to create guides and models of organizational planning of urban areas that can be followed and applied in cities to implement sustainable development (Amado and Ribeiro, 2011). Thus, it is crucial to the definition of land use policies that take into account sustainability criteria (Reidsma et al., 2011, Huseynov, 2011).

Most existing studies seem to agree and point to the concept of cities with tall buildings, high-density construction areas and minimization of land occupation with low needs for materials and transport, as a solution for the development of sustainable cities (Cho and Lee, 2011, Feng and Xingkuan, 2011, Wener and Carmalt, 2006, Doughty and Hammond, 2004, Senbel et al., 2003, TGCCP, 2010). Doughty and Hammond assert that a cluster of high-density buildings, as long as having a well integrated network of infrastructure and transportation systems, can improve the energy efficiency of cities and reduce their environmental impacts (Doughty and Hammond, 2004). Compact cities may have an important role to ensure the efficient use of resources in certain urban areas because they can be designed to improve the energy efficiency of the built environment, promote the use of public transport and non-polluting alternatives such as cycling and walking and further improve the reliability of waste recycling and reuse of materials and products.

However there are other studies that consider different aspects for the design of sustainable cities. For example, Shan and Xingkuan only consider aspects of aesthetics and art in building, completely neglecting aspects related to the environment, society and economy (Xingkuan and Shan, 2011). Huseynov believes that cities must contain large green spaces to be considered sustainable (Huseynov, 2011). Ramos and Rocha go in the same direction and consider important the existence of green corridors within cities (Rocha and Ramos, 2012). Cho and Lee emphasize the importance of the satisfaction of the inhabitants in sustainable communities, mainly addressing the social component (Cho and Lee, 2011). Mendes also believes that one aspect to consider is the quality of life of the population (Mendes, 2004). Bragança et al. consider the importance of the orientation of buildings due to the planning of public roads to reduce the energy consumption of cities (Bragança et al., 2004). Newman develop the concept of sustainable city - based infrastructure system high efficiency in order to reduce the environmental impacts associated with transportation and car dependence (Mitchell and Casalegno, 2008).

2.3 *Sustainability assessment in the development of sustainable city models*

Nevertheless, these studies did not seek to define the criteria that cities should check holistically to be considered sustainable, focusing only on some aspects. This neglects the complexity of the interrelationship and interdependence of the various issues that must be addressed together in the development of sustainable cities. This multidisciplinary approach to sustainability is recognized in studies dedicated to sustainability assessment of buildings, in which criteria are defined encompassing various aspects simultaneously (Mateus and Bragança, 2011). And these criteria can be adapted to the urban level for the development of sustainable urbanizations (Amado and Poggi, 2012). The evaluation of sustainability of urban environments is very important. Danko and Lourenço argue that sustainability assessment is the first logical step in the development of plans to improve sustainability in urban environments. A preliminary assessment of levels of sustainability of each case allows an efficiency of time and resources that are related to the complex tasks of data acquisition, analysis and problem solving, which usually occur in such operations (Danko and Lourenço, 2007). Taking this into account, some existing studies seek to define indicators for assessing the sustainability of urban environments. Silva and Mendes developed an assessment indicator for air quality and acoustic comfort in cities (Silva and Mendes, 2012). Silva also developed an index for the assessment of sustainability related to urban mobility in cities (Silva et al., 2010). Danko and Lourenço developed a set of indicators to assess the sustainability level of urban wastewater management systems (Danko and Lourenço, 2007).

There are also some studies that define criteria for the evaluation and development of sustainable buildings and cities holistically. Wener and Carmalt, indicate that a sustainable city must have sustainable high density buildings and establishes criteria for sustainable buildings that can be extrapolated for a sustainable city. Thus, a sustainable building should take into account the comfort and health of occupants, minimizing the consumption of energy and materials, encouraging healthy ecosystems (Wener and Carmalt, 2006). Robertson refers the importance of defining a multidisciplinary team in the design of a sustainable city (Robertson, 2012). Rosales also agree that the definition of sustainable city should take into account a holistic view of sustainability, highlighting the importance of using indicators to quantify the levels of sustainability (Rosales, 2011).

2.4 *Economy and sustainability in cities*

Some studies have a different approach, indicating that in order to a city become sustainable, it must be self-sufficient in terms of energy, materials, food and water. Grewal and Grewal define a self-sufficient city as one that is able to meet their basic needs without reccuring to importation (Grewal and Grewal, 2012a). Grewal and Grewal proved that a city can be totally independent in energy using currently available technologies (Grewal and Grewal, 2012a) and be independent in food production, with the adoption of modern production technologies such as efficient vertical farming (Grewal and Grewal, 2012b). These authors demonstrate the importance of increasing the self-sufficiency of cities because this property boosts the efficiency and sustainability in resources usage, increasing the autonomy and economic resilience against the negative effects of the global economic crisis.

Despite this, some authors are critical of the concept of self-sufficient cities, and say that it is an utopian concept (Parkin, 2000) (Doughty and Hammond, 2004). They assert that sustainability is a desirable and attainable goal globally, but do not agree that is achievable locally. However, they recognize that the causes of the problems of current cities are the excessive importation and unnecessary transportation of resources. Parkin considers that the implementation of sustainability in cities puts severe restrictions on the economic development of countries and companies and therefore can be considered impractical in the short or medium term, pointing to 2050 or after 2100 to achieve progress in the implementation of sustainability on the planet taking into account the current conditions (Parkin, 2000).

However, some authors argue that in sustainability, the economic aspects should not be considered and that the problems that should be addressed are those related to the environment and its load capacity, as well as the population life style (Senbel et al., 2003) (Lewis and Brabec, 2005, Feng and Xingkuan, 2011). Senbel argues that ecology and the implications of human consumption patterns are two environmental aspects that are not well represented on metrics based on economic performance (Senbel et al., 2003). Lewis and Brabec agree stating that the key factor in the analysis of a pattern of urban planning in sustainability is actually quantifying their impact on the ecological systems (Lewis and Brabec, 2005). In fact, many authors seem to point the economic development as an obstacle to achieve sustainability. Fresco considers that the current economic model is the main cause of unsustainability in cities and in the world (Fresco, 2007). The circular city and society envisioned by Fresco promotes equality between citizens and since the existence of money can cause inequalities, Fresco has created a new system to replace the monetary system, often called a "resource-based economy". This system has gained particular notoriety and receptivity in recent years as a result of the financial collapse. Thus, it becomes important to consider the social aspects of equality related to economic aspects in the operation of cities and communities.

2.5 *Considering human behaviour in the development of sustainable cities*

Taking this into account, another research field that is very important and supported by a vast number of authors is that the development of sustainable cities must consider social issues and the willingness of inhabitants. Wener and Carmalt claim that sustainable buildings and therefore sustainable cities should be designed to meet basic human needs, taking into account the psychological effects and behaviors of individuals. Also the success of a sustainable city model, based on a good technical and environmental performance, depends largely on the degree to which designers are able to understand and predict human behavior and activities and their ability to use this knowledge to develop spaces that meet these needs (Wener and Carmalt, 2006).

Fonseca and Ramos also argue that inhabitants should be involved in the decision-making processes related to urban planning policies (Fonseca and Ramos, 2004). Girardet concept of sustainable city is that the organization of spaces should allow its citizens to meet their needs, improving the life quality without damaging the natural environment or the quality of life of neighboring populations, present and future (Girardet, 2008). Amado, highlights the importance of defining city models taking into account the wishes of the local population and concludes that public participation is mandatory during all stages of the organization of the territory in order to ensure a proper relationship between the community and the proposed urban form (Amado et al., 2010). Robertson and May highlight the importance of considering the social aspects stating that given the complexity of the interactions between humans and the environment, solutions to environmental problems cannot be purely technical and therefore cannot be divorced from social, cultural and politic aspects (May, 2008) (Robertson, 2012). Ross goes further and says that if the current cities ever develop into sustainable cities, will be due to social and political change and not due to technical improvements (Ross, 2011). Fresco agrees and says that long ago that there are technical means for the implementation of sustainability in cities and it is in the hands of citizens to act to implement sustainable practices (Fresco, 2007).

2.6 *Existing sustainable city models*

Although there are many studies about the characteristics that cities must fulfill to be sustainable, there is a lack of studies in which there are proposed new sustainable cities models. The first studies on models of urban planning cities began in the nineteenth century with the expansion of industrialization and increasing population migration to cities. In 1923 Burgess proposed the circular city model with concentric functional rings. This model was applied to the city of Chicago. It contains a strong industrial and business center and concentric rings of residential areas of increasingly higher classes as the distance from the center increases (Barcelona Field Studies Centre, 2013).

After the concept of Burgess, several models have emerged throughout the twentieth century. For example the model of Hoyt in 1939, also known as sectarian model and the model of Harrys and Hullman and 1945, also known as multi-core model (Figure 2) (Adhvaryu, 2010).

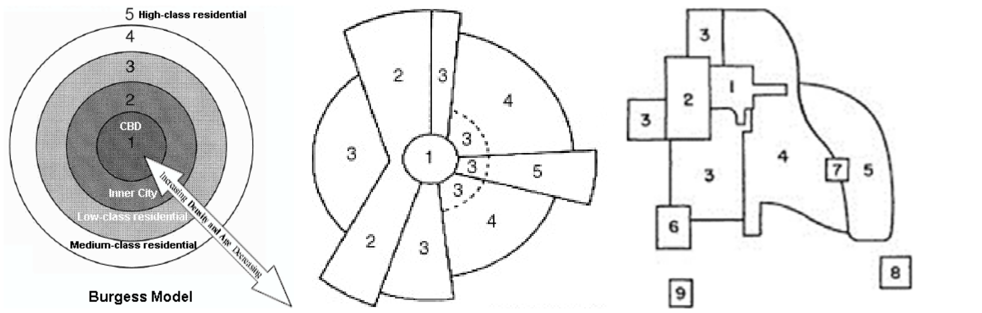

Figure 2. Burgess model (left), Hoyt model (centre) and Harrys and Hullman' model (right)

Despite the existence of these classic circular models of cities evolution, many existing cities evolved from a grid model, often organically and with little planning. There was not a true effort throughout history to implement sustainability models in cities. In part this was due to economic constraints but also due to the fact that these models attempted to exploratory understand the expansion of cities, rather than be sustainable cities models. In fact, the issues related to the carrying capacity of the planet and sustainability only began in the late twentieth century.

However, recently some initiatives with the objective of designing and building sustainable cities emerged. For example, Mendes proposes in his book "The future of cities" the implementation of an innovative conceptual model in midsized Portuguese cities, the concept of incubator city, based on the implementation of five dimensions, the intellectual city, the innovative city, the connected city, the authentic city and sustainable city (Mendes, 2011). Another example of a model that has raised notoriety in recent years is the one from Jacque Fresco, which idealizes a circular city with functional concentric rings, through the application of the latest technology to protect the environment and improve the lifestyle of populations. The city model of Fresco

(Figure 3), designed for cities up to one million inhabitants, adopts a resource-based economy, in a model where all waste is recycled and all energy comes from renewable sources, with efficient management of materials and resources (Fresco, 2007). Another example of a sustainable city model is the EcoTownZ project (Figure 3), a model of an ecological city with 150.000 inhabitants, which follows the traditional urban forms and can be built using current technology. The creators of the model claim that the city offers the best of urban and rural environments simultaneously and they can completely eliminate the traffic problems, promoting the use of public transport, cycling and walking (EcotownZ, 2008). Despite the existence of these models, there have been many critics of these models, as the implementation of a city of this type may involve building a city from scratch, being very difficult to adapt an existing city to the idealized model of sustainability.


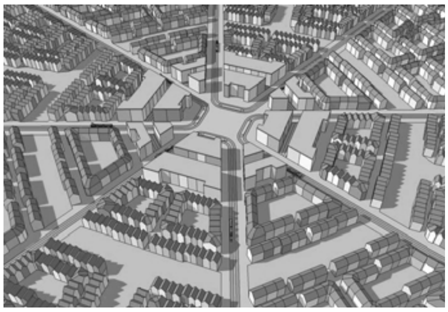

Figure 3. Sustainable city models: Fresco (left) and EcontownZ (right)

2.7 *Urban regeneration examples*

Despite some examples of cities being built from scratch, mainly in Asia, most of the existing efforts in the implementation of sustainability measures in cities have been conducted through the urban regeneration of existing cities. A common example is the city of Stockholm, in Sweden, which was considered the first European Green City by the European Commission (EC, 2010). Also in Sweden, the cities of Göteborg and Hammarby Sjöstad are also referred to as sustainable cities. There are numerous private and public initiatives to implement sustainable labels in cities, especially in northern Europe and the Scandinavian countries. As an example, the cities of Bristol, Leicester and Middlesbrough in England, Nantes in France, Rotterdam in the Netherlands, Aalborg, Ballerup and Frederikshavn in Finland (100 % of renewable energy), Oslo in Norway, Copenhagen in Denmark , Vitoria- Gasteiz in the Basque Country and Frankfurt , Freiburg , Hamburg and Kronsberg, in Germany, among others (EC, 2013).

However, these examples do not follow a long term urban regeneration model in order to transform current cities in sustainable city models. In these cities, there are efforts towards sustainability, which is commendable, but it can be argued that these efforts do not encompass all aspects of sustainability holistically and are not enough. The titles of "green city" are thus assigned improperly since there is the promotion of some individual measures that are recognized as interesting for the implementation of sustainability but the cities are not really sustainable as a whole.

Despite these recent plans (21st century), there are much older examples such as the case of Paul Grover plan to transform the city of Los Angeles (which is usually considered unsustainable) in a sustainable city. The plan includes changes to the technical design and in social, political and economic levels over 20 years to become a sustainable city (Grover, 1983). However, Grover's plan was never implemented and continued only as a proposal. The city of Los Angeles has evolved a lot since then and has greatly increased its environmental impact, being a case study in water importation at great distances. This poorly planned growth occurred in many cities around the world, in which there are technical means to implement improvements to make them more sustainable, but in most cases there is a lack of financial ability and/or politic willingness to embark on this kind of plans. It is therefore very important to study and develop sustainable cities models and ways to implement these models in existing cities.

3 CONCLUSIONS

The development of sustainable cities is a very complex subject. However it is urgent to act at this level to mitigate the environmental and social problems that are present in nowadays cities and societies around the world. To develop a sustainable city, environmental and social aspects must be balanced, while being especially careful in dealing with economic issues.

It is important to note that the development of a sustainable city should be subject to sustainability assessment. Only with the use of sustainability assessment it is possible to compare holistically different models and decide on the implementation of the best solutions. In this evaluation, it is important to define a relevant set of quantifiable indicators. These indicators should respond to a set of criteria that cities should check to be considered sustainable.

A city can only be sustainable if the population is in harmony with its operational model, since the behavior of a community is determinant in the performance level that can be achieved. Several authors even relate the concept of sustainable city with the concept of sustainable community, since they are interdependent. Taking into account that in the design of a sustainable city, the communities operations should be considered, such as consumption patterns and lifestyle of the population, the opinions of the population must be predicted and studied in the design of a sustainable city. Thus, the design of a sustainable city model bounces off the strictly technical subject and addresses axiological issues related to the wills of people individually and collectively.

Finally, it is necessary to take into account that considering the state of development of most cities, it is difficult to implement some models of sustainable cities. In fact, many cities are implementing sustainability measures, disregarding sustainable city models. However, these measures prove to be insufficient for implementation of sustainability holistically. So it becomes necessary to study urban regeneration plans for long-term implementation of sustainable cities models.

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Chapter 10

Design for Life Cycle and Reuse

Buildings' connections and material recovery: from deductive to inductive approach

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ABSTRACT: Recent researches on building construction and deconstruction seem to suggest that, from a theoretical point of view, the criteria for buildings' connection selection might lead to scenarios of total material recovery and would allow the closing of the material loop cycle. This paper presents the first step of a research that aims to create a knowledge base about the relation between buildings' connections and material recovery. As in Architecture were building design is often approached with top-down strategies, main literature consulted also presents a top-down thinking in building connections and joining framing were these themes hardly are the central focus. Therefore, as an alternative, a bottom-up or inductive approach to buildings' connections is necessary in order to obtain a more solid knowledge support on the topic. Connections' classifications need to be linked together in order to form a larger view of connections complexity and related issues.

1 INTRODUCTION

Architecture is a field “trapped” between art and industry, between aesthetic and function, between pure concept and technology. The multiplicity of aspects that Architecture must attend to, translates into a slow and almost schizophrenic process of changing practices. On one hand, sustainability seems to be part of current architectural speeches and practices, but at the same time the majority of Architects still seems to postpone its actual implementation. The appeal launched by Albert Dubler, President of the International Union of Architects (UIA), in February 13th 2013, for architects to strongly commit to a universally responsible and Sustainable Architecture reveals how this field has a peculiar timeframe to embrace change towards sustainability. As Siza Vieira recently acknowledged in an interview (- 2013), Architects can be responsible for how some of the buildings they design are increasingly less able to withstand the effects of time and changes in usage.

This passive behavior of Architecture in particular, and Construction Industry in general is explained by existing legislation codes, limited external technology interrelation, scattered chain of responsibility (material manufacturers, designers, constructors, users, operators) and conflict of interests between long term and short term perspectives of stakeholders (Kibert 2002).

Sustainability concerns regarding energy flows and consumption were the firsts Construction Industry had to respond to, due to extensive developed legislation codes and certification systems in these areas. But other major concerns like water and waste management, heritage preservation or sustainable rehabilitation, for example, are still inconspicuous or beginning to be dealt with by Construction Industry due to the complexity of its implementation.

2 OBJECTIVES AND METHODOLOGY

This paper general framework is on waste management of building materials related concerns. More specifically on design and solutions for life-cycle and reuse.

Buildings' most significant characteristics— individuality, longevity, dimensional characteristics, diversity of constituent parts, unlimited form possibility, programatic and functional variety, in site construction and significant human labor assembling— make them unique products.

They have been designed as static products with very little capacity to adapt over time in order to respond to the continuously changing demands of societies.

The enormous consumption of materials in Construction Industry resulting from building construction, transformation and demolition is leading to enormous natural resources deploitation and waste generation.

Although the Construction Industry is already starting to replace commonly used demolishing processes by deconstruction processes, not only for environmental reasons but also economic and legal, the results are still scarce.

Buildings and its constituent parts have not been and rarely are being designed to be adapted, deconstructed, disassembled or demountable, at any stage of their life-cycle. That caused researchers to think about closing the material loop cycle— whether or not it is applicable to buildings.

Some researchers suggest that design for deconstruction increases the potential for material recovery for reuse and recycling both at building's life-cycle and construction operations (Crowther 2000, Kibert 2002).

Furthermore, some researchers suggest that connections' characteristics is one of the main aspects to consider since the design phase, regarding the enhancement of material recovery (Crowther 2000, Durmisevic 2006).

Therefore, from a theoretical point of view, it seems that buildings' connection selection criteria might lead to scenarios of total material recovery and would allow the closing of the material loop cycle.

This paper puts forward the deepening of research on buildings' connections and joining as a fundamental element for the successful progress of buildings' material recovery. As a first step on this research, this paper intends to identify the approach strategy to adopt on future work developments.

The first section of this paper starts with a generic review of three main buildings' materiality related issues: building composing elements, deconstruction processes and end-of-life scenarios.

Subsequently this paper contextualizes joining and connections through a preliminary approach to literature divided in distinctive parts: design goals and opportunities and joining and connections classification.

Each section is concluded with briefs discussions on the subject.

This paper concludes with a discussion about the suitability of deductive or inductive approaches as the next step to obtain a more solid knowledge support on the topic.

3 BUILDINGS' MATERIALITY

Buildings are built with different types of elements— materials, components and systems —, joined by connections and assemblies through in-site operations that assembly all these elements into the final building. At the most basic level, buildings, as all its elements are made of materials.

Therefore, the deduction that acting on the problematic of material recovery is primarily dependent of in-site operations over all of its elements through deconstruction processes seems to be valid. As well as the premise that buildings' types of elements determine deconstruction processes results and subsequently end-of-life scenarios.

In order to support theses premisses, the first section of this paper looks at literature to contextualize the three main issues related to the materiality of buildings'—building composing elements, deconstruction processes and end-of-life scenarios— followed by discussion.

3.1 *Building composing elements*

A general classification of types of building elements was found on literature (Kibert 2002). A review is presented redirecting the main focus from manufacturing features to in-site assembly features.

From material to systems, all elements can be divided in five general categories:

- Site-installed products, systems and components; manufactured (with little or no in-site processing) (e.g. bricks, boilers);
- Site-assembled components; engineered, off-site fabricated (e.g. structural steel, precast concrete elements, engineered wood products);
- Site-finished products (in-site dimensionally and technically dependent); off-site processed (e.g. cast-in-place concrete, asphalt, aggregates, soil);
- Site-processed products (in-site dimensionally dependent); manufactured (e.g. drywall, electrical wiring, insulation, piping);
- Site-installed low mass products; manufactured (in-site functionally and technically dependent) (e.g. paints, sealers, varnished, glues, mastics).

3.2 *Deconstruction Processes*

Three types of deconstruction processes, organized according to material/building components and connections conditions after deconstruction were identified in literature: (Beitz 1996, Sonnenberg 2001, Lambert & Gupta 2005, Klett 2009). An aggregation of the different approaches could be read as follows:

- Destructive: both connections and material or components are damaged;
- Partly destructive or semi-destructive: connections are destroyed during deconstruction without damaging components. (Reuse in construction is possible through connection replacement.)
- Non-destructive: neither connections nor materials or components are damaged. (Reuse in construction is possible; recovery of materials and components with higher levels of quality). Non destructive deconstruction can be of two types:
    - Reversible: deconstruction process similar to the inverse of construction.
    - Semi reversible: deconstruction process more complex than corresponding construction process.

3.3 *End of life options*

The main end-of-life options in waste management found on literature resulted in a list of nine generically ordered by its priority order (Crowther 2000, Morgan & Stevenson 2005):

- Prevention of waste;
- Reuse (products, systems or components) without any operations;
- Refurbishment (products, systems or components) through small repair operations;
- Remanufacturing (products or components) through disassembly, overhaul and replacement operations;
- Recycling (material recovery operations);
- Incineration with energy recovery;
- Incineration without energy recovery;
- Landfill.

3.4 *Discussion*

Each of the identified types of building elements exhibits different material recovery constraints, deconstruction potential and end-of-life scenarios (Crowther 2000).

In addition, end-of-life hierarchy is not static or closed because different materials exhibit different potential for recycling or reuse (Kibert 2002). Also because new materials and new waste processing technologies will certainly appear.

Further development on lexical and definitions is needed to clarify the subtle interferences between each of the listed concepts, both on types of building elements, end-of-life scenarios and processes.

4 JOINING

This section looks to contextualize research on joining and buildings' connections through a preliminary approach to literature on the subject. The underlying contributions will then be identified and addressed.

Contrary to initial expectations, there has been little research that focused specifically on buildings' connections. So, it was necessary to extend the search field to other areas were connections and joining raise some similar questions, like mechanical engineering.

Similarly, the literature found was more scattered that initially expected. In addition, the focus were more frequently oriented towards product manufacturing issues or the design of connections to respond to predefined product oriented goals instead of more global points of view.

As a result, three broader approaches to connections and joining were found inside the field of Mechanical Engineering (Sonnenberg 2001, Messler 2004). And two other inside the field of Architecture, more oriented towards buildings' specificity (Durmisevic 2006, Meijs & Knaack 2009). They are presented and then discussed.

4.1 *Joining design goals and opportunities*

Four major reasons for joining were identified. They are organized according to design goals (Messler 2004) that can also be understood as design enabling opportunities.

Functionality:

- carry or transfer loads in products;
- product size and/or shape complexity;
- multi-material product;
- product portability;
- product disassembly;
- product damage tolerance;
- product performance.

Manufacturability:

- product structural efficiency;
- material choice optimization;
- material consumption optimization;
- product size and/or shape complexity;
- on-site assembly systems and structures.

Costs:

- material choice optimization;
- material consumption optimization;
- minimize material weight and maximize structural efficiency;
- manufacturing alternatives;
- automation of assembly;
- product maintenance;
- product service,
- product repair;
- product upgrade;
- reduce life-cycle costs;
- responsible disposal.

Aesthetics:

- application of finishings different from underlying materials;
- form and shape complexity.

4.2 *Joining and connections classifications*

Two major classifications of connections and joining methods were found.
They are very similar structures but one is focused on fundamental primary forces used in different joining processes (Messler 2004) while the other focus on fastening methodology (Sonnenberg 2001).
To present a more clear discussion both are presented as they raise different questions.

Classification according to fundamental primary forces used in different joining processes (Messler 2004):

- Mechanical Joining (Mechanical forces)
  - Mechanical Fastening
  - Integral Attachment
- Adhesive Bonding (Chemical forces)
  - Using Adhesives
  - Solvent Cementing
  - Cementing/Mortaring
- Welding (Physical forces)
  - Fusion Welding
  - Non-fusion Welding
  - Brazing
  - Soldering
- Variant Processes
  - Braze Welding (Physical forces)
  - Thermal Spraying-Metals/Ceramics (Physical forces)
  - Thermal Spraying Polymers (Chemical forces)
- Hybrid Processes
  - Rivet-Bonding (Mechanical/ Chemical)
  - Weld-Bonding (Physical/ Chemical)
  - Weld-Brazing (Physical)

Classification according to fastening methodology (Sonnenberg 2001):

- Discrete fasteners
  - Threaded fasteners
  - Non-threaded fasteners
- Integral Attachments
  - Locators
  - Locks
  - Compliant
- Adhesive Bonding
  - Acrylics
  - Cyanoarcrylates
  - Epoxies
  - Anaerobics
  - Silicones
  - Polyester Hot Melt
  - Polyurethane
- Energy Bonding
  - Soldering
  - Brazing
  - Welding
- Others
  - Seaming
  - Crimping
  - Zippers
  - Velcro
  - Etc.

Two other classifications were found. They introduce building design principles when defining connections in design phase (Meijs & Knaack 2009) and constraints resulting from different types of connections and joining methods (Durmisevic 2006).

Principles of construction about components connections (Meijs & Knaack 2009):

- Location of connections
  - Internal connections
  - External connections
- Type and function of connections:
  - Joints according to position of components:
    - butt joints;
    - open joints;
    - overlapping joints;
    - crossing joints;
  - Joints according to the form of components:
    - direct;
    - indirect;
    - mixed.
  - Joints according to the material components.

Although the relation between fastening methods or joining processes is not clearly addressed, a classification according to degree of flexibility of connections, from fixed to flexible (Durmisevic 2006) is presented in order to establish relation with deconstruction issues.

Classification according to degree of flexibility of connections (Durmisevic 2006):

- direct chemical connection;
- direct connections between two pre-made components;
- indirect connection with third chemical material;
- direct connections with additional fixing devices;
- indirect connection via dependent third components indirect connection via independent third component;
- indirect with additional fixing device.

4.3 *Discussion*

While there are distinctive aspects in each of the classification schemes proposed by these researchers, the overall approaches complement each other and concern about common issues.

Nevertheless, the lexical and definitions are not yet stabilized: joining, fastening, connecting, etc.

Relations between design goals and joining processes are scarce and need to be deepened to create a more clear and complete body of knowledge about this topic.

Some attempts however, are already being made and are introducing new ways to approach joining and connections for building design.

Some examples are recent researches focusing in strategies to create compatibility between industrial building products from different manufacturers, like flexible interfaces typology between building components (Nijs et al. 2010) or universal and all-purpose solutions for structural unions and infill elements (Del Aguila 2010).

Also, some practical applications of design strategies concerning material recovery through detailed definition of connections and joining are being tested. One example is the pilot project “Efficiency House Plus with Electric Mobility”, completed in December 2011 in Berlin, developed under commission by the Federal Ministry of Transport, Building and Development (BMVBS), that was designed by the office of Werner Sobeck using the patented Triple Zero Concept. One of the main goals of the project was resource efficiency. Both material selection and application planning were, from the beginning of the design phase, oriented towards separation and return to material cycle through deconstruction. The building planning and construction allowed the identification of practical limitations and constraints regarding scenarios after use of building materials or building components, including possible uses and recycling methods (Sobek 2012).

5 CONCLUSIONS

Architecture is a holistic field where building design is often approached with top-down or outside-in strategies. That is, it is common practice to begin with general contextualization, with low levels of detail characterization, and then approach to the specificity of each building detail.

In this process, connections are mostly an auxiliary step in final stages of construction detailing were the overall design principles or contexts are no longer present.

Moreover, this paper shows that main literature consulted reflects this top-down or deductive thinking in building connections and joining framing. These thematics hardly are the central focus.

As result, it became clear that as alternative, a bottom-up or inductive approach to buildings' connections would be suitable in order to obtain a more solid knowledge support on the topic.

In order to deepen research on buildings' connections and joining, as a way to successful buildings' material recovery, material and components end of life scenarios and deconstruction processes need to be researched from buildings' connections and joining point of view. And not the opposite.

An inductive approach, instead of a deductive one, would allow the observation and analysis of buildings' connections and the identification of the constraints that they introduce on deconstruction processes and end of life-scenarios. Consequently, it would enable the formulation of strategies to buildings' connection selection in order to achieve total material recovery.

Instead of the deepening of the research on a limited set of connections' types resulted from a deductive approach to literature on the topic, an inductive approach would allow the research of a broader set of buildings' connections' types and the establishment of a set of relations between buildings' connections, deconstruction processes and end of life scenarios.

At this stage of the research, it is already possible to identify some near future works.

Connections' classifications need to be linked together in order to form a larger view of connections complexity and related issues.

Also, a more stable lexicon on buildings' connections and joining is of great need.

The dependency relation between buildings' connections classification and material end-of-life scenarios also needs to be deepened and clarified.

Finally, the influence of connections and joining in material conditions after deconstruction processes needs to be established and detailed in order to support the creation of knowledge base that, in a more distant future might support design and evaluation tools that can assist the creation of more sustainable buildings.

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Against Over-materialization. Architecture of Negatonnes

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ABSTRACT: The building sector and specially architecture as influential player on global resources flows market should take responsibility to create an effective sustainable development, reducing embodied overloaded components, material hegemony and wasteful energy consumption or emergy level. Global consumers material culture dominates our ordinary behaviors with enormous materiality level increase – kind of physical objects spam. Nations or societies can be characterized by different models of materialization and various scales of its environmental impact in long time perspective. Architecture and construction methods, life cycle phases of maintenance and deconstruction should be dematerialized as much as possible to be an imperative of radical green buildings against over-materialization processes observed in urbanized societies today. Various dematerialization models and definitions such as : re-materialization, re-location, de-carbonization are presented with main target: how to determinate eco – efficiency of buildings and quality of life in built environment for future generations. Architects should recognize dimensions of dematerialization, and its consequences and opportunities of relative and apparent dematerialization to know, how to enrich shaping spaces with minimal architecture of negatonnes and immateriality.

1. MATERIAL CONTEXT OF ARCHITECTURE AND DESIGN

Each year growing energy and materials consumption in built environment is a proof that global economy, even in financial crisis is still resources hungry. Consumers material culture dominates our ordinary behaviors with enormous materiality level increase – kind of physical objects spam. On the level of building sector and specially architecture is influential player on global resources flows market, responsible for incredible amount of wastes generation. Architects and designers should take responsibility to create an effective paths of sustainable development, reducing embodied overloaded components, material hegemony and wasteful energy consumption or emergy level. To improve eco-efficiency of new buildings and products or existing ones, we have to change production and distribution policies in a radical and practical way. We need the radical change in designers material culture.

There are many consumers needs which can be realized without a necessity of buying a material, physical product with its functional form of matter. Hire a product for short term or calling an appropriate service, can our needs be satisfied and in the same way we can reduce materials and energy consumption fulfilling consumers needs in sustainable way, promoting simple form of product dematerialization.

Physical products for example washing machine can be replaced with high quality laundry service. We could eliminate private cars increasing effective mobility service. We don't need radiators in our homes, when appropriate heat supply will satisfy our feeling of comfort. Many goods we collect for own can be replaced with rental service. We observe a process how virtual forms of information (e-mails, e-paper, e-books) eliminate materialized forms of information (letter, fax, paper documents, ect.) from our ordinary life (Janikowski, 1998). Materiality is a common face of contemporary architecture, very often first impression effect is achieved with variety or extravagance of materials use in different forms of space compositions. Focusing on housing stock, materials density per capita in urbanized areas is still growing. Our houses and offices are overloaded with matter, which is connected with growing energy consumption, emissions levels including specific microbiological pollutions of indoor climate. From global point of view, real sustainable architecture development is too slow and still it is not a main stream in creation of city fabric wellness or living city organism. Material hegemony of architecture and design should be changed with dematerialization process.

Different definitions of dematerialization exist in a public domain, sometimes narrowing interpretation to mass reduction in a product or replacing its meaning with another terms such as transmaterialisation, optimization, digital conversion, profit increase mechanism, etc. Following sustainable development idea in general, dematerialization can be define as a reduction of materials or/and energy use in existing or only creating products or services to minimize negative environmental impact without compromising the ability of present and future generations to meet their own needs.

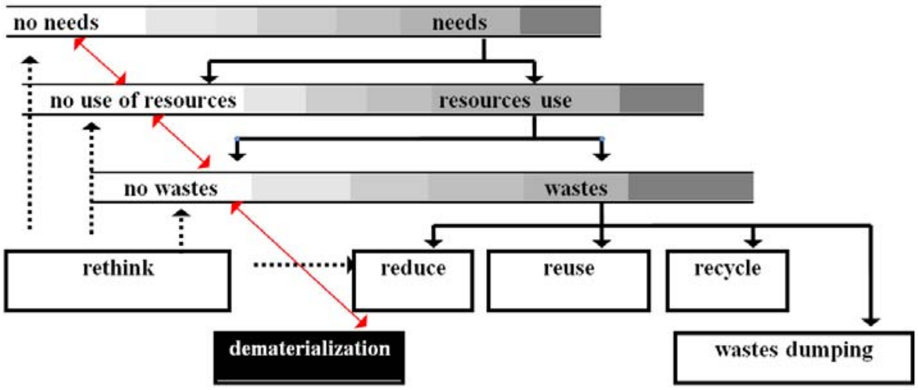

Figure. 1. Relations between creating consumers needs and tones of wastes generation as dematerialization context in architectural design.

Today looking for high quality living, „more and better", offered by economical growth, in reality can be replaced with "less and worse". Present consumers society creates more and more needs, incredible number of goods, facilities or building structures – everyday material objects of desire, which produce problematic tones of wastes and emissions.

2. IDENTIFICATION OF DEMATERIALIZATION DIMENSIONS

Dematerialization can be applied in different scales and various physical dimensions. We should treat it as a kind of dynamic and holistic process witch starts early in product programming and planning phase, where first sketches and misty ideas appeared. First drawings, functional programs, basic measures, materials components or energy concepts can be identified as a 2D dimension.

Building spatial models of products or buildings and searching relations between another objects located in physical space is a next step, defined as a 3D dimension. Studying proportions and material or energy flows between objects and buildings in space (physical space treated as valuable, not renewable resource too) is important for scale of dematerialization in exact moment. Next added measure is time factor which creates a 4D dimension where for example aspects of product life cycle management or life cycle costing (so influential for dematerialization process) can be analyzed in long life perspective. Going forward - a 5D dimension is a matrix of different simulations of products or buildings, generated for different life cycle scenarios (e.g. variations for end of life scenarios, "life after life" architecture) activated in dynamic time - space dimension. On predesign or design level, dematerialization process can be optimized using virtual simulations in 5D dimensions matrix. Implementing comparative methods and multivariate analysis, one of the most effective, simultaneous dematerialization model can be explore form matrix of virtual design proposals. Each analyzed, dematerialization model can be characterized with different simultaneous data including inter alia: negawatt power (an amount of energy saved) or negatonnes (an amount of mass saved or recycled) per functional product unit in a life span, extracted from mentioned matrixes. Kilograms of saved and not used building materials create visual representation of dematerialization potency, we can call it in picturesque way as an “architecture of negatonnes”. But negatonnes is not only parameter of dematerialization. We have to respect and to control a total budged of carbon emissions with focus on de-carbonization process as a part of dematerialization agenda. Of course pre-design or design stage of product, object or building is highly influential part of dematerialization process, but another phases of life cycle are important too. For example deconstruction stage as a part of the Cradle-to-Cradle design idea seems to be crucial for reuse or recycling old resources for new products in closed loop economy. Recovery of not used products or structures, old materials salvation and renovation creates enormous opportunities for architects and designers. Searching a new catalog of reused materials we can choose between the linear economy system (based on brand new materials and products in context “Take, Make, Dispose”) or the circular economy system (based on renewed or recycled materials in context “Waste is Food”). Dematerialization leads to regeneration because reduces environmental impacts and creates imaginary “architecture of negatonnes”, as a kind of parallel worlds, still unknown but ready to discover.

3. IMPLEMENTATION OF DEMATERIALIZATION PROCESS

Locally, for the investment process and globally, for national economies dematerialization process implementation is complex activity with demand of different, interdisciplinary actors engagement and cooperation. It is necessary to considerate different models of dematerialization in early design and planning stage. To find potential of mentioned models it is necessary to discover scale of impact to biotic and abiotic environments just in prenatal phase of new products, objects or buildings, having in mind creation for immaterialized economy with reduced entropy factor.

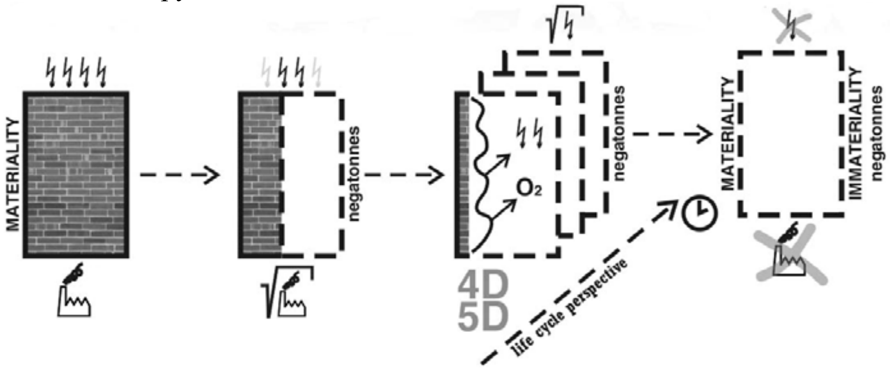

Figure 2. Phases of dematerialization process in architectural design

A new plan of acting - a kind of „road map” showing possible sectors of ecological efficiency and relations with dematerialization process is needed. Materials, energy or capital savings potency can be identified in four fields of activities (such as: production processes reengineering, products redesign, markets rethinking, components and wastes revalorization) related to product, building or urban complex whole life cycle framework. On this base we can discover different models and scales of dematerialization.

The simplest, one dimensional model is focused on single variable (size, volume or mass) in modified and analyzed product, object or building structure. The relative or apparent reduction of materials used per product unit is the most common aspect examined in this model and its consequences on economical and environmental assessment. Wastes minimization or resources efficiency in a production process or in any functional product unit in its life cycle framework is another aspect of described model contemplation. Another sub option of one dimensional model can be considered including minimization or optimization characterized with number of materials reduction. Substitution or re-materialization are focused on material replacement as another variation of mentioned model similarly to transformation described as material replacement with service.

Another model of dematerialization is two dimensional, with focus on material and energy consumption influences. Complex, three dimensional model of dematerialization is taking in consideration total emissions next to resources and energy consumption in long life cycle perspective. Dematerialization as an economic phenomenon is of interdisciplinary nature. When narrowing it to the building sector the need of involvement of many investment process participants must be highlighted. It is connected with changing of foregoing vertical hierarchy of information into horizontal one in frame of created, often ad hoc, interactive network system.

4. CONCLUSIONS

Dematerialization in architecture has different forms, takes place in a different scales, is comprehended and interpreteted in different ways. Besides esthetical, business and vogue issues, the ecological motivation of dematerialization implementation, which arise from readiness to cut down the antropopressure, is the need in the framework of quick and irreparable changes in biosphere. Ecological motivations of dematerialization can be based on arousing conscience of wasting society or on forming social and ecological intelligence. Such activity shown in sustainable architecture should be a guarantee of renewal of harmonious relations with biotic environment and favours comprehension of dynamic phenomena which keep the ecosystems in vitality.There are a lot of tools and helpful strategies which allow successively to implement dematerialization process in economy. In the architectural design, systems of ecological certifications of buildings, sustainable building and ethical investment systems as well as digitization with BIM modelling and internet tools development of open network society seem to be extremly useful.

The important intermediate stage of dematerialization is rematerialization meant as the revision of technology and materials well-used. The purpose of rematerialization is an increase of long-term productivity solution used in building and architecture, minimalization of wastes and polution what set the first determined step into sustainable architecture. Applying biodegradable materials or possible to reuse / recycle ones will influence the way of designing as well as cause changes on building materials market, formal and esthetic changes in executed objects and will have an impact on space users' behaviour.

Undoubtably the main idea in promotion of dematerialization and sustainable architecture should be economic, social and ecological harmonization what gains the kind of dynamic state of self-support for systems and minimalization of entropy level.

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Opportunities and obstacles of implementing transformable architecture

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ABSTRACT: Due to inadequate design many building materials are lost whenever a building no longer meets contemporary needs. Those adaptations are labour intensive because disassembly is difficult and not planned. However, by implementing the time dimension in design, a structure will be (re-)build transformable and can respond to changing requirements of society and individuals.
The last few decades design strategies and approaches were developed to facilitate change and the reuse of building parts; nevertheless time-based architecture is still restricted to a small scale and specific functions. To identify the causes in the specific case of Belgium, a qualitative survey of the market leaders of the Belgian construction sector is made. Besides the bottlenecks of implementing transformable building in Belgium, the potential opportunities and the necessary steps that must be taken in order to build in a more transformable way are interrogated too.

1 INTRODUCTION

Despite the fact the construction industry is responsible for 30% of the total waste production and 50% of the extracted raw materials (Eurostat 2008), Belgium remains building in the same (static) way. The main part of construction and demolition waste is in fact recycled, but the recycling process occurs often with a quality descent by mixing different materials (OVAM 2011). For instance concrete rubble is almost exclusive reused as foundation material for roads and only 5% of the concrete rubble is used again in high-qualitative concrete applications (Vrijders & Desmyter 2008).

The need for new buildings materials and the production of waste will be minimized by implementing the time dimension in the design phase. Therefore, buildings can more easily anticipate functional, technical or social changes during their life cycle. Namely by using compatible components and reversible connections, building components can be added and removed to fulfil new requirements. The removed components can be reused later on in a new configuration.

The last few decades architects, designers and researchers developed design strategies and approaches to facilitate change and the reuse of building parts; nevertheless transformable building is still restricted to a small scale and specific functions, such as temporary / transitional buildings.

To identify the causes in the specific case of Belgium, a poll of the market leaders of the Belgian construction sector was made. The data was collected with the aid of a long and short online inquiry, face-to-face interviews, and a workshop.

Besides the constraints and downsides of implementing adaptable constructing in Belgium, the potential opportunities and the necessary steps that must be taken in order to evolve to transformable buildings were questioned. The people surveyed had to answer in which concepts they think their target audience is interested and in which not. Finally, it was examined which time-based principles are already implemented and it was interrogated if the contacted organizations are interested in some concepts.

2 THE STRUCTURE OF THE SURVEY

The online survey consisted of clustered questions: general and open questions, questions concerning the implementation and demand on building level, on component level, and on material level and questions concerning dismantling and marketing. The interviewees could pass over a cluster of questions if they were not applicable for their organisation. This implicates that not all questions are answered by as many interviewees. The questions are based on literature wherein transformable concepts are defined, such as (Durmisevic 2006). Unlike the online survey which contained direct questions**,** the face-to-face interviews and the workshop were conceived as a discussion and as a brainstorm session about the theme.

Insofar five interviews can provide a certain indication, it seems an organisation is more positive in an online inquiry about its own realisations of principles regarding to transformable building than it is in reality. During the interviews it seems the organisations implement less than was indicated in the poll.

The survey yields 66 independent organisations; consequently this is a qualitative research and not representative for the whole construction industry. Nevertheless clear insights emerge. Thirty individuals attended the workshop and we took five face-to-interviews. A low response rate of a short version of the survey was remarkable: of the 240 sent surveys, just 4 completed surveys returned, while for a twice as long version of the online inquiry 30 of the 165 inquiries returned entirely. The difference: the short version was send to arbitrarily chosen organisations, offices, etc. of the constructing industry; whereas the long version was send to market leaders and innovative companies of the construction industry. The low response rate of the short online survey can be explained by a lower interest of the industry in general.

The largest group of respondents is producer of building materials and components (24%). (Fig. 1) Additionally, architects, researchers, consulting firms, governmental institutes and information centres replied the survey in high numbers too; whereas only a minority of contractors and educational institutes were reached. Though, in reality contractors are the largest group of the construction industry. A low interest in transformable building of the contractors could be the cause. The respondents are mainly private organisations (74%).

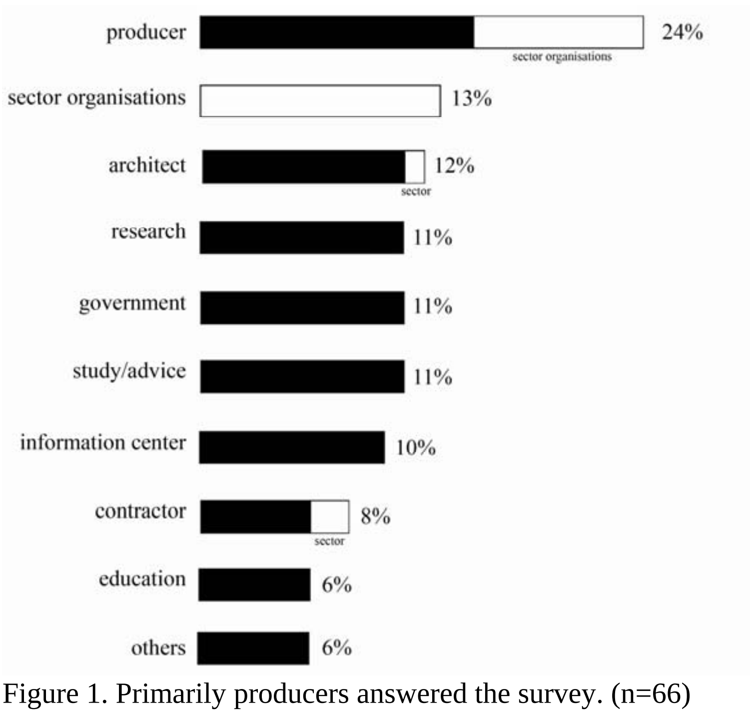


Figure 1. Primarily producers answered the survey. (n=66)

3 OUTCOMES OF THE SURVEY

3.1 *Opportunities*

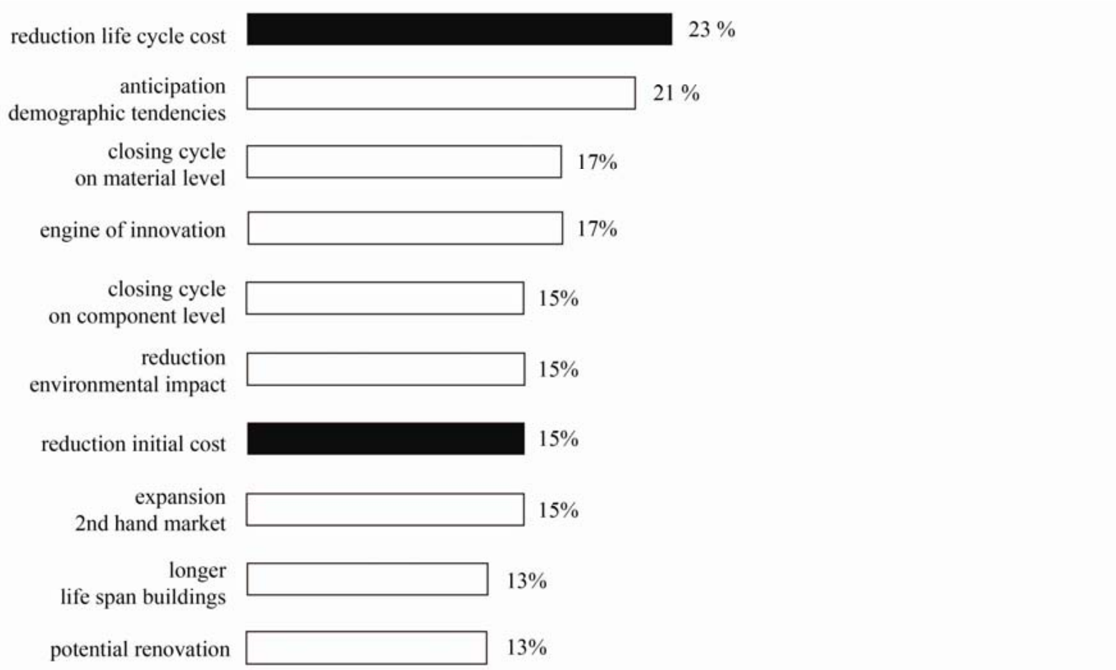


Figure 2. A reduction of the life cycle cost is the most often cited as a possible opportunity of dynamic building. (n=53)

A first question examined if the organisations polled agreed that there are opportunities linked to time-based (re-)constructing. It is remarkable that all people interviewed answered this question positively. They could specify this answer by mentioning what they think adaptable architecture can change exactly in a positive sense.

Figure 2 points out the most quoted opportunities. Interesting to see is that many people consider a reduction of the initial and the life cycle cost as a potential of transformable architecture for example by using 2nd hand and standardised components. As well as more economic advantages, like transformable architecture as an engine of innovation and an expansion of the 2nd hand market, there are of course potentials in the area of ecology too: the closing of the cycles on material- and component level, the reduction of the environmental impact and the extension of the life span of buildings. Most of the economic opportunities are established in a recent study by TNO, the Netherlands Organisation for Applied Scientific Research. (Bastein et al. 2013) In their study the opportunities of circular economy for neighboring country the Netherlands are supported by figures.

On social level the anticipation of demographic tendencies was pointed out frequently as a potential. To conclude, some other interesting opportunities mentioned are an easier maintenance, the possibility to lifelong living, more intense use of space, and a higher value real estate.

3.2 *Demand*

In a second part we asked the respondents if they think there is a demand from their audience for applying dynamic principles. A majority reacts on this question very positively (64%) and 21% thinks their target group is possibly interested if some obstacles are overcome. Only 3% indicates their audience isn't interested and the other people surveyed don't know. Consequently, a majority is positive about the request from their target audience to implement transformable principles. Those percentages are equal if the interest of the organisations' audience in more specific concepts is asked. A survey made in the Netherlands confirms this assumption. In this study more than 70% of the examined residents declare the space plan of his dwelling does not meet his needs. For this reason 30% of the families living in these dwellings would like to move out; additionally 45% would like to stay if the dwellings could be adapted to their needs.

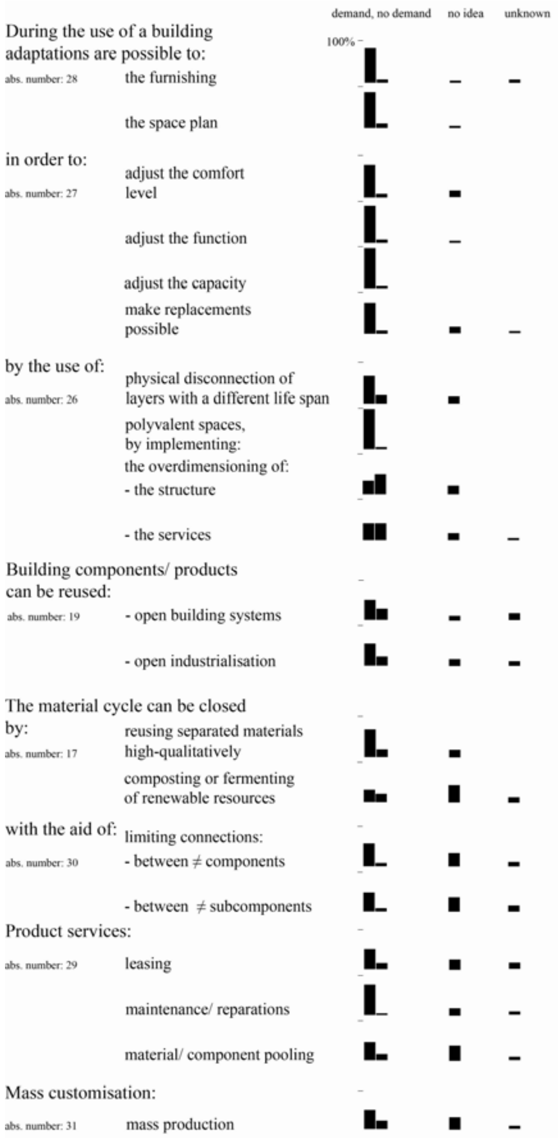


Figure 3. The people interviewed think their target group is interested in most of the concepts regarding to dynamic building.

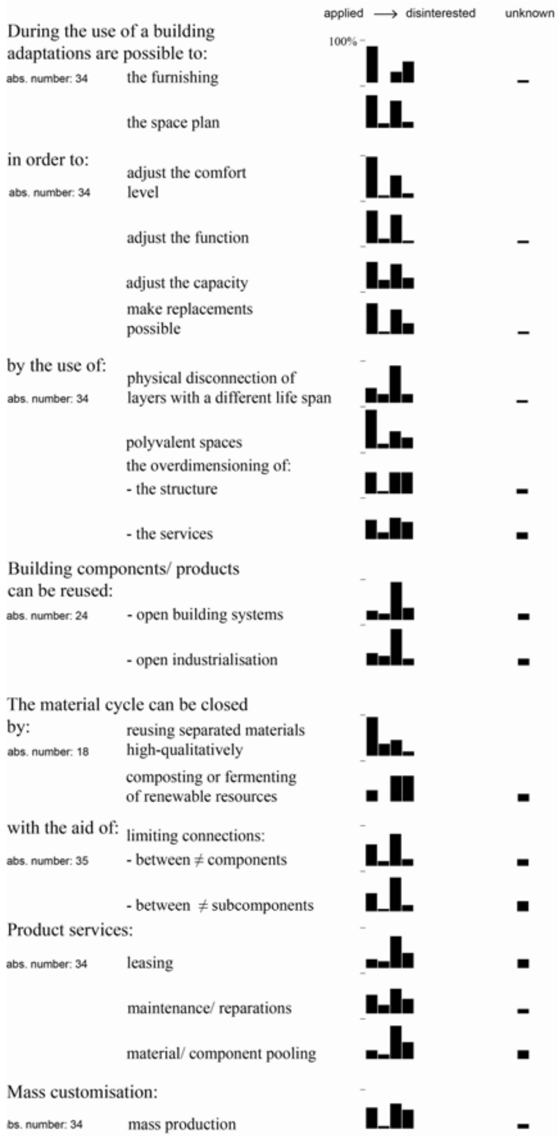


Figure 4. Apart from a few exceptions, many dynamic concepts are already applied or the respondents are interested to apply them. The gradation goes from applied, planned, and interested to disinterested.

(Marsman & Smit 1999) Figure 3 points out some significant statistics of the answers of the interviewees on the questions with regard to the demand for time-based architecture from their target group. The questions could be answered with ‘there is a demand’, ‘there is no demand’,

‘I don’t know’ and ‘unknown’. A majority believes there is a large market to make transformations possible in order to change the function (89%) and the capacity (96%), above all by the use of polyvalent spaces (96%). Closing the cycle by composting and fermenting of materials after use scores the worst. For this principle just 29% indicates there is a request. Although, 41% answers this question that he doesn’t know the answer and 12% reports he’s unfamiliar with the concept. As a result it can be concluded that the people interviewed can little imagine relating to closing the biological cycle according to the *Cradle to Cradle* concept. Another less scoring principle is the overdimensioning of the structure (32%). For more technical principles, like limiting the number of connection between different components (34%), the people polled don’t know if their target group could be interested; while open building systems are a relatively unknown concept, since 16% don’t know the meaning.

3.3 *Application*

The abovementioned was demanded a second time, but now to know if the organisations are interested to apply certain concepts regarding adaptable (re-)constructing. First, it was asked if the people polled would like to realize principles concerning dynamic (re-)building. A large majority answers this question positively (71%) and even 21% reveals they already apply certain principles. The others don't know.

The percentages concerning the application of transformable constructing are higher than first generally indicated when more specific concepts are examined (37% average). However, as pointed out before, the respondents seem in an online survey to be more positive about their own realisations of principles regarding to time-based architecture than they have in reality. During the interviews it appears the organisations implement less than was indicated in the inquiry. Figure 4 shows the most remarkable outcomes about the implementation and interest in concepts concerning adaptable (re-)building. The gradation goes from applied, to planned, interested and uninterested.

As mentioned before, many organisations are already implementing concepts. For example, the furnishing (52%) and the space plan (47%) are at present often designed adaptable in order to make replacements (44%) more easily and in order to adapt the comfort level (59%), the function (47%) and the capacity (38%), by for instance the use of polyvalent spaces (55%). More technical concepts, like the physical disconnections of functions with a different life span, are less frequent applied (21%). Like expected, open building systems are solely little applied (13%), as well as for product service systems (from 11 to 26%). Composting or fermenting of building materials is minimal implemented and a minority is interested (16%).

The interest to implement certain concepts that are not yet applied is often high but for the most part of them there are no concrete plans to realise them. This high interest in transformability by the construction industry is shown in the results of a similar survey by Paduart too, where she questioned architects and social housing associations. (Paduart 2012)

The *upcycling* of materials, or in other words the separated collection of materials to reuse them high-qualitatively and the use of semi-open building systems are the most often planned to apply (both 17%).

There is less interest to overdimension the structure and the services in order to make adaptations possible (30% and 27%). In addition, mass production is a less popular concept too, since 35% is uninterested.

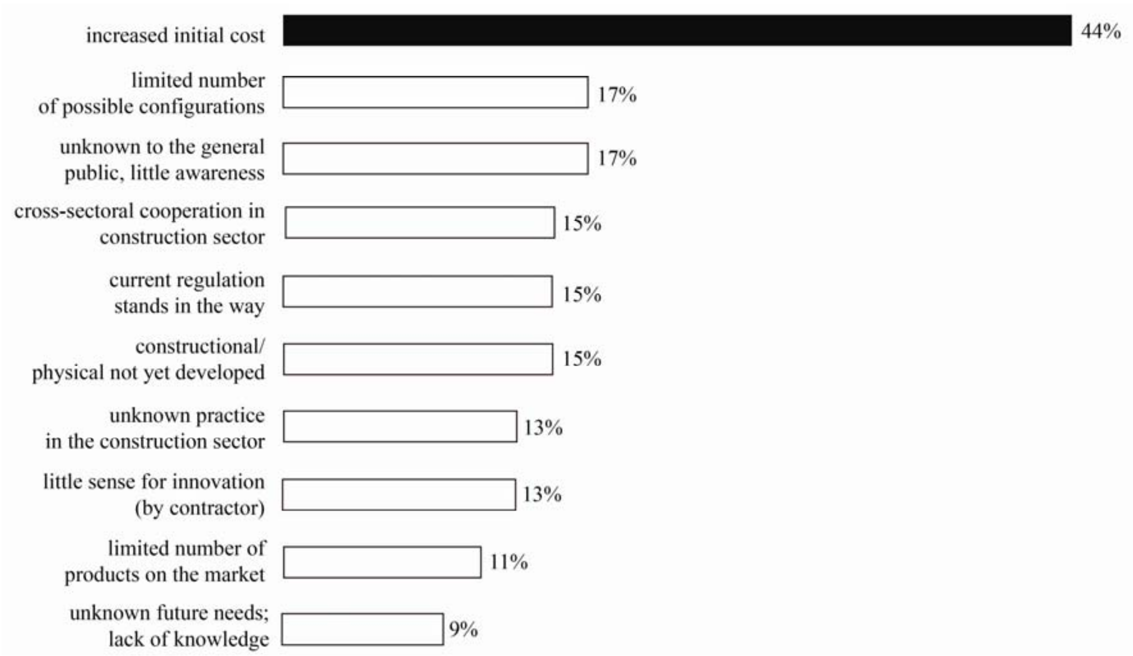
All concepts are known by a majority. More technical concepts are less known, like the reduction of the number of connections between different components (for 14% of the surveyed unknown). The concept open industrialisation is unknown for 9% of the people, although, because some people polled indicates they already apply this concept (17%), while in reality this is still nowhere applied, we can conclude that this concept is the less known. A same conclusion can be made for the upcycling of materials. A survey in Czech Republic confirms that several sustainable principles are still unknown for most producers. (Sramek et al. 2013)

3.4 *Obstacles*

All people polled are convinced that the realisation of dynamic constructing cannot happen without obstacles. Mainly an increased initial cost is seen by a large group as the impediment to conquer. (Fig.5) However this is a misunderstanding, the second most important impediment according to the respondents is a limited number of possible configurations. The opportunities of open building systems are not yet known by the respondents; and the fear for uniform, standardized houses is present. For this reason the people surveyed are related themselves to one of the other crucial barriers: 'unknown practice in the construction industry'. According to some of the respondents the concept is still unknown to people; additionally, people have little awareness of the importance of closing the material cycle.

Other important obstacles are associated to a lack of knowledge: the concept is not yet constructional and physical developed and there is a lack of general knowledge in order to apply dynamic principles according to the interviewees.

Figure 5. A higher initial cost is a potential bottleneck of dynamic building according to a majority.



(n=54)

3.5 *Disadvantages*

In addition we interrogated the respondents about possible downsides of transformable architecture. Three-quarters of the interviewed believes there are shortcomings and only a minority (13%) thinks there are no disadvantages. The other people surveyed don't know.

Equally to the primary quoted impediments the increased initial cost is again the most cited. (Fig. 6) Moreover, in this category there are some misconceptions too, viz. less esthetical value and a restricted architectural freedom.

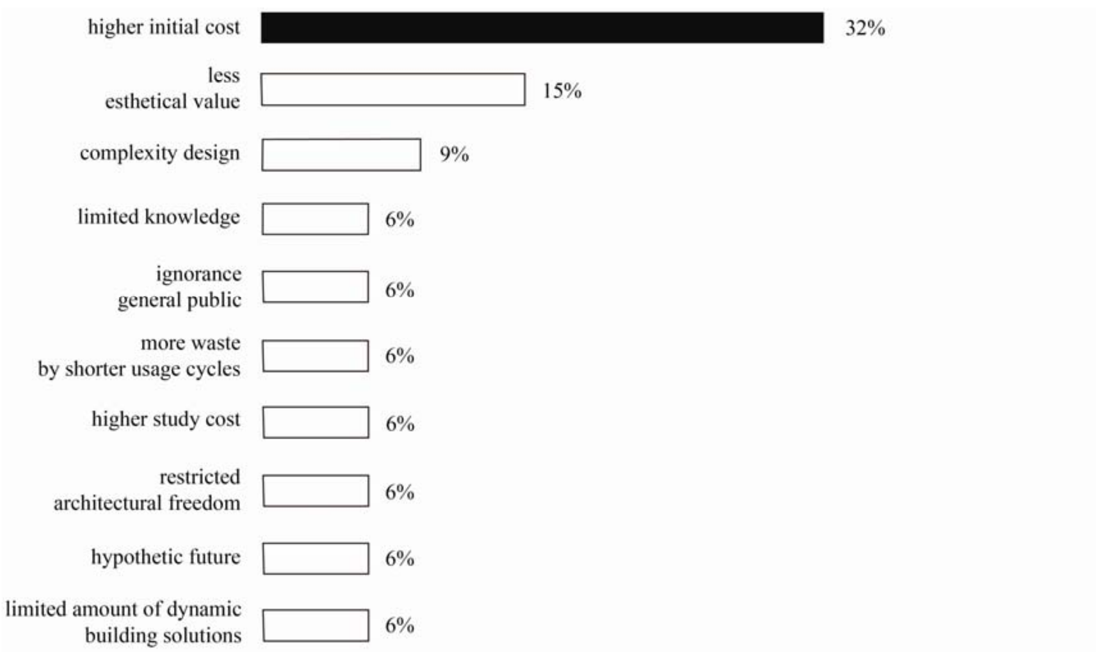


Figure 6. An increased initial cost is the most often cited as a disadvantage of dynamic building. (n=29)

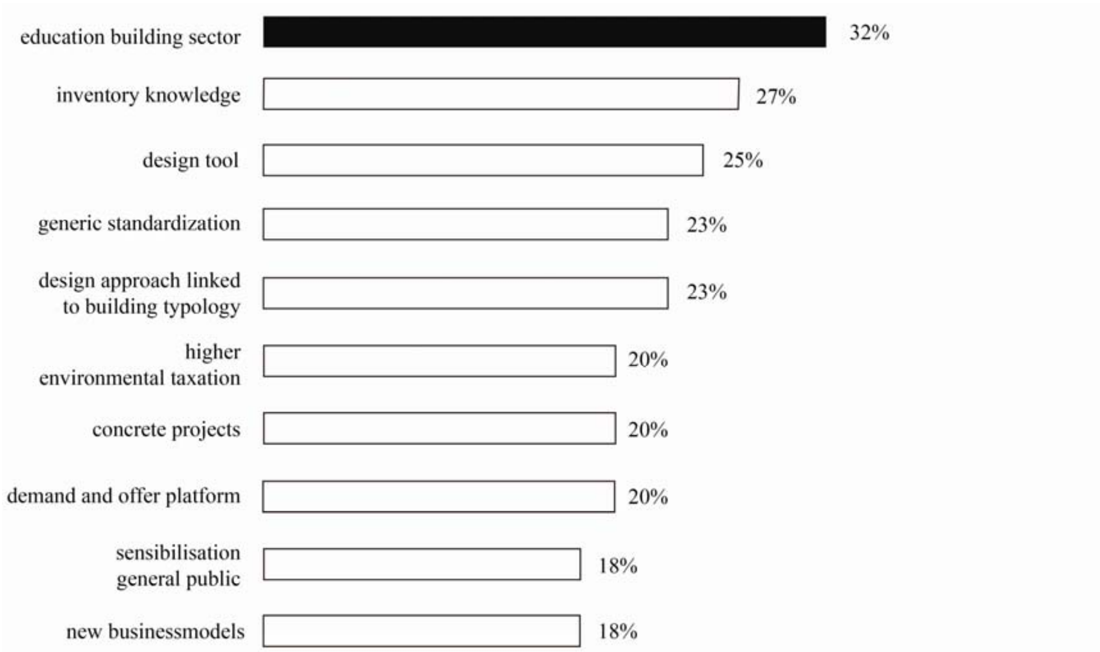


Figure 7. For a large part of the interviewees, there are still many needs that have to be resolved before dynamic building can be applied.(n=44)

3.6 *Needs*

To provide an answer to those bottlenecks and downsides as described above, the respondents propose in the first place a (re)education of the construction industry. Furthermore there is, according to them, an urgent need to make an inventory of the existing knowledge regarding to dynamic architecture. A decision tool must be created too in order to support architects during the complex design process. Some respondents report an important role for the government by the sensibilisation of the surplus value of reuse, and by stimulating concrete projects, e.g. with aid of subsidies and higher environmental taxation. At the present time, there should be anticipated to many more needs before transformable structures can be applied; the most important needs according to the people interviewed are revealed in Figure 7.

4 CONCLUSIONS

Despite this survey is not representative for the whole Belgian construction industry, some insights appear. Several insights are confirmed by other international studies. As a result it can be assumed that most of the results are valid in a broader international context. This research underlines the demand from the market leaders of the constructing industry to implement time-based concepts. Additionally, all people interviewed think there are opportunities related to dynamic building. Many people consider a reduction of the initial and the life cycle cost as the main potential of transformable architecture. But at the same time, an increased initial cost is seen by a large group as the impediment to conquer.

A majority would like to realize principles concerning dynamic building and many respondents think there is a demand from their audience for applying dynamic principles. Even 21% reveals they already apply certain principles.

However, the low response rate of the short online survey can be explained by a lower interest of the industry generally. Only a minority of contractors could be reached, while contractors are in reality the largest group of the construction industry. Moreover, the organisations who did react still don’t know the meaning of certain transformable concepts. In addition, there are certain misconceptions. For instance, the fear for uniform, standardized houses is still present. All people polled are convinced that the realisation of dynamic constructing cannot happen without obstacles. According to a majority the concept is still unknown; and there is a lack of knowledge to apply dynamic principles. At the present time, there should be anticipated to many needs before transformable structures can be applied.

These insights can be used for further studies of the transition towards building dynamically.

5 ACKNOWLEDGMENT

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Multiple design approaches to transformable building: construction typologies

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ABSTRACT: Considering the increasing dynamism of our society, contemporary building practice is characterised by a widening gap between the functional and technical lifespan of most assets. Consequently, designers are challenged to apply strategies that anticipate change and avoid abandonment or early demolition.
Life cycle analysis has proven that transformability has the potential to be a more sustainable strategy to build than those that are currently used. Nevertheless, several unresolved design questions and a higher purchase cost prevent the widespread implementation of such transformable structures.
In response, a broad literature study and two case studies gave rise to the design strategy 'partiality transformable building'. This paper discusses several construction types for partially transformable building and a systematic study identified the types' potential to anticipate change in multiple ways.

1 INTRODUCTION

1.1 *The challenge to anticipate change*

Continuously improving construction techniques greatly increase the quality of buildings and lengthen their potential, technical lifespan. However, most technical services, the building's skin and space plan elements do not reach that age but are altered earlier. Traditionally, dwellings with an intended lifespan of 60 years begin already to change within three years after completion and are entirely refurbished at the age of 25 (Tros et al. 1999). Those refurbishments are driven by social as well as demographic evolutions such as changing family structures and an unprecedented aging. Moreover, it is expected that these evolutions will accelerate even further. As a result, the building's actual, functional lifespan still shortens(Schwehr & Plagaro Cowee 2011).

Traditional buildings that are constructed in a static way remain vacant, are thoroughly refurbished or even demolished when they no longer meet the owners' needs. That can be illustrated with current vacancy rates of office buildings reaching 11.5 per cent in Brussels and iconic demolitions, e.g. Pruitt-Igoe in 1972 (Woodford & Kuljanin 2012). Thereby all energy, material and financial resources are lost. The inert characteristics of traditional buildings become even more problematic when they are linked to acknowledged ecological and socio-economic consequences such as the serious depletion of the earth's mineral and fossil energy resources and the enormous waste flows construction industry introduces(European Environment Agency 2012). All these consequences considered one understands that resources should be well spent and designers are challenged to apply strategies that anticipate change.

1.2 *Strategies and concepts surmounting the gap*

In reaction to the gap between the technical and functional lifespan of traditional buildings, architects H. Hendrickx and H. Vanwalleghem proposed the design strategy 'transformable building'(De Wilde & Hendrickx 2002). In order to build in a transformable way, two key concepts are generally maintained: a'generative dimensioning system' constitutes together with 'design for disassembly' a set of exchangeable and demountable components of which transformable buildings are composed.

Transformable buildings can be easily altered and foster the reuse and recycling of entire constructions, single components and their materials (Durmisevic 2006). As a result, the problematic material and waste flows are countered. The two key concepts considered, transformable buildings and their components can be given a new function, prolonging their functional lifespan until it reaches their technical one. As a result, the gap between functional and technical lifespan can be surmounted(Debacker et al. 2007).

1.3 *Questioning the ultimate solution*

Characterised by both demountable and exchangeable components, Kit-of-parts are frequently proposed as the ultimate approach to transformable building (De Temmerman et al. 2012). Kit-of-part systems are a special form of prefabrication because of their clean and controlled building process, their potential to be assembled automatically and their capacity to be assembled and dismantled repeatedly. Unlike the majority of prefabricated components that are permanently connected at the time of construction, kit-of-part systems encourage the construction of transformable buildings and a life cycle management of their components (Howe et al. 1999).

Kit-of-parts have been a recurring theme in historical studies and pilot projects (figure 1). Particularly within the context of an open industrialisation, the High-Tech movement, Metabolism and Dutch Structuralism designers aspired after reconfigurable systems in order to reconcile the mere standardisation of construction components with individual needs. Although examples such as the recyclable XX-office by architect Jouke Post (1999, Delft) and the reusable low-tech-high-performance ABT-office building by Hubert-Hencket architects (2001, Delft) illustrate the potential of kit-of-part systems, they simultaneously reveal a plethora of unresolved questions such as the suitable construction sequence, the need for overcapacity and the size of a basic unit(Leupen et al. 2005). In addition, a higher purchase cost prevents the widespread implementation of compatible components and demountable systems for transformable building (Durmisevic 2006).

Figure 1. The XX-office by architect Jouke Post (left) and the ABT-office building by Hubert-Hencket architects (right) are two Dutch projects that successfully illustrate the potential of kit-of-part systems, but simultaneously reveala plethora of unresolved design questions. Photos by the architectural offices.

2 LITERATURE AND CASE STUDIES

2.1 *Introducing additional time-depended design aspects*

In response to the design-related questions concerning kit-of-parts, a broad literature study on time and change in design has been elaborated. In addition to transformability's two key concepts, a 'generative dimensioning system' and 'design for disassembly', numerous other time-dependent issues were found (figure 2)(Galle 2011). That might not be surprising since also social and cultural concerns play an important role within the architectural design.

For this broad research, literature from different fields was consulted. Publications of various types, including papers, technical reports, essays and project discussions, by multiple groups of authors, including governmental organisations, researchers, designers and censors were explored. The collected time-dependent issues were grouped in four aspects that could be clearly distinguished through all consulted discussions on time and change in design. They imply significant consequences for a building's potential to deal with changing demands or its resistance against them. Together they form a framework for the analysis of multiple approaches to the design strategy 'transformable building'

First, it is essential that components are not damaged during use, disassembly, handling or transport. Therefore 'durability' plays an important role. Second, 'versatility' can be introduced prior to transformability. Simply by their generic qualities, such as a straightforward accessibility, bright illumination or generous space plan buildings can respond to multiple requirements and house many functions. Third, 'building management' through an accurate monitoring of the users' needs and an according allocation guaranties an efficient use of the available facilities. Finally, in addition to the technical requirements of users or standards, a building's functional lifespan is also determined by the 'sociocultural value' that is addressed to it(Galle 2011).

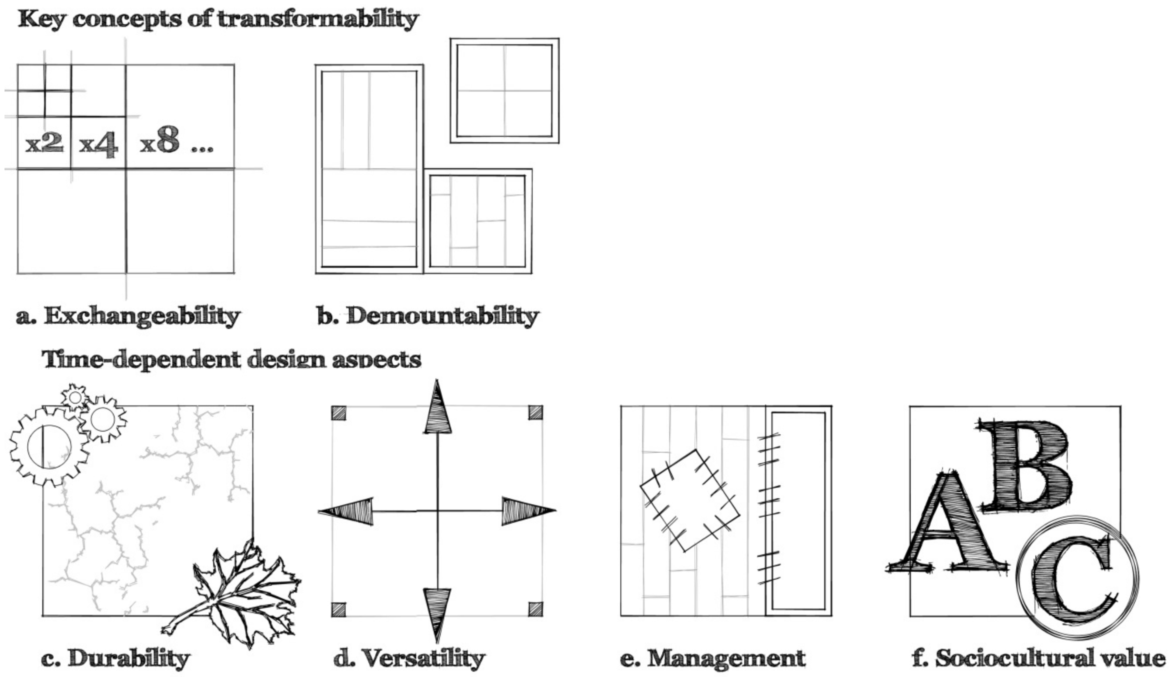

Figure 2. Two key concepts of transformable building are completed with four time-dependent design aspects after a broad literature study, constituting a framework for the analysis of multiple approaches to the design strategy 'transformable building'.

2.2 *Validation of the time-depended design aspects*

In order to explore the usefulness of the elaborated framework, aimed at analysing or designing transformable buildings, two case studies have been elaborated: (figure 3)the Hypotecaire Beleggingskas (HBK) bank office originally designed by architect Willy Van Der Meeren (1923-2003) and the Medical faculty housing (La Mémé) designed by architect Lucien Kroll (born 1927)(Galle & De Temmerman 2013).For both cases, the framework of key concepts and additional change-related design aspects allowed a comprehensive analysis of the projects' design concepts and process and indicated their capacity to deal with change as well as their shortcomings.

However, these case studies also revealed that the relation between specific design concepts and the more general design aspects of the presented framework is not unambiguous. In both cases, multiple design approaches were found that take position within the idea of change and transformability, and different aspects of the analytical framework are thus compiled in diverse design concept.

Consequently, the case studies showed that, it would be hard for a designer to balance the aspects of the framework since there is no one-to-one relation between the analytical framework and the architectural design of transformable buildings. Moreover, each architectural assignment has its unique context.

Furthermore, the case studies illustrated that however the aspects are acknowledged in literature and designers are aware of their advantaged during the redesign of buildings, they are rarely reconsidered and implemented in practice.

Figure 3. The analysis of the HBK bank office (left) and La Mémé (right) illustrated the applicabilityof the time-depended design aspects that were derived from literature. Photos by the first author.

2.3 *Proposing a comprehensive design strategy*

After the findings of the two case studies, the design strategy 'partially transformable building' is proposed. Partially transformable building has the intention to be a more feasible implementation of transformability than kit-of-parts. Like the HBK bank office and La Mémé faculty housing, partially transformable buildings combine static and transformable building parts. Transformable building parts can be altered without difficulty and cope with changing users' needs and standards. Their components can be easily dismantled and efficiently reused or recycled, anticipating problematic resource depletion and waste flows. The building parts most evident to be transformable are the building's stuff and space plan. Those are the most vulnerable for fashion and have the shortest lifespan. However, also technical services, the buildings' skin and load bearing structure can be designed in a transformable way, enabling change in the long term.

In complement, static building parts can be introduced. They guaranty a financial feasibility, reliable technical quality and are commonly available. Their inability to be altered should however be countered through the introduction of durability, versatility and a well-taught management. The building part that is the most evident to be static is traditionally the load bearing structure(Galle & De Temmerman 2013).

3 PARTIALLY TRANSFORMABLE CONSTRUCTION TYPES

3.1 *Layering, generic space and the frame*

In order to provide the design strategy ‘partially transformable building’ of useful implementation possibilities, four alternatives to kit-of-part systems are studied in the final part of this paper. The proposed construction types are derived from professor Leupen’s thesis ‘Frame and Generic Space, a study into the changeable dwelling proceeding form the permanent’(Leupen 2006).

Leupen recombines five ‘Functional layers’ (Structure, Skin, Services, Space plan and Access) and presents an overview of no less than thirty-two construction types. Those types are of great interest since they proceed from a traditional, inert frame and facilitate a transformable infill and thus fit the idea of partially transformable building. The types that are used in the rest of this paper are those wherein only one layer constitutes the permanent frame and the others can be altered easily (figure 4).

A critical adaptation of those construction types will offer guidance for designers and will further introduce partially transformable construction types in the research on transformability. Each type is studied in multiple ways, including the preconditions of the permanent layer and the relationship between the permanent and transformable layers. This study does however not emphasise the conceptual and spatial qualities that are already insightfully illustrated by Leupen, rather it focuses on technical and functional as well as social and cultural aspects.

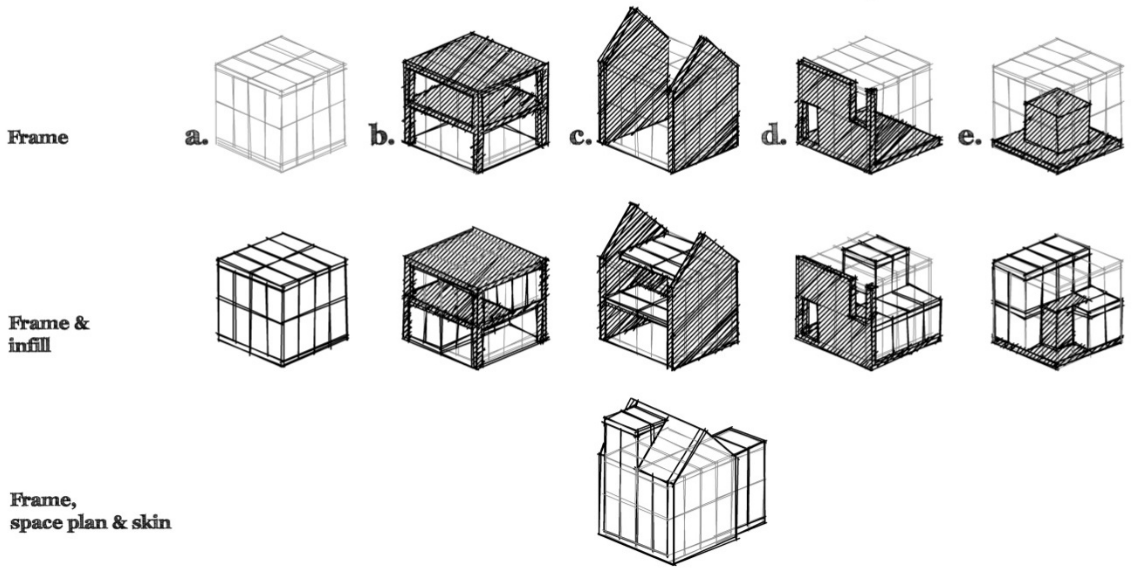

Figure 4. In contrast to kit-of-part systems (a.), the proposed construction types for partially transformable building combine a static frame and a transformable infill. The discussed types are the Base-building type (b.), the Structural wall type (c.), the Façade type (d.) and the Structural service core type (e.).

3.2 *The Base-building type*

The Base-building type proceeds from its permanent, load bearing structure. A structure conceived as a grid of columns offers spatial versatility in two directions. In contrast, a sequence of cross walls sets limits the maximum space width. Both permanent frames have fixed ceiling heights, but those could include multiple stories or have openings providing versatility in the third dimension. Considering overall stability and structural stiffness, additional cores or wind bracings are indispensable. Bearing those constraints in mind from design stage already is thus crucial for the building’s appropriate versatility and related longevity.

The Base-building construction type is widespread in contemporary high-rise office buildings and multi-story dwelling blocks. Materials that are generally used for the load bearing structure are concrete and brickwork. They are preferred because of their high compression strength, low cost and common availability. Unfortunately, few construction techniques allow the realisation of a demountable and reusable load bearing structure. However, an inert load bearing structure might be very durable. Its technical lifespan can reach up to several hundreds of years. Additionally, a Base-building can provide a reliable sound- and fireproof compartmentalisation.

A Base-building's versatile floor plan facilitates a transformable infill. Given that only the structure is permanent, space plan, skin as well as technical services can be composed out of demountable and compatible systems. The structure's dimensions implement a possible generative dimensioning of those systems. Consequently, the combination of permanent and transformable building layers requiresa well thought engineering and well managed exploitation of both frame and infill.

3.3 *The Structural wall type*

Similar to the Base-building, the Structural wall construction type emerges from its intransformable but durable load bearing structure. According to the Structural wall type, that structure is conceived as two or more parallel cross walls. Buttress walls can guarantee overall stability. Since there are no floors, the distance between the walls becomes all-decisive. That distance is determined by both functional and economic preconditions. The Structural walls offer a rigid seclusion of multiple compartments and corresponding versatility: the floor area is extendable in depth and height, whether repetition of the type is eligible perpendicularly to the walls. Consequently, this type is the most suitable for terraced houses.

Similar to the Base-building the building's skin, space plan, services and access can be built in a transformable way. Since the structure is strongly compartmentalised and generally no additional partition walls are needed, technical requirements are low. Consequently, the Structural wall type demands little management and enhances customisation and subsequently the user's appreciation. When multiple dwellings should be integrated between two walls, infill can be conceptualised as independent sub-structures according to a box-in-box layout. Apart from local planning regulations, it is the total building depth that determines its functional versatility taking into account daylight penetration, ventilation and accessibility. Traditional urban terraced houses perfectly illustrate the advances of this construction type(Pfeifer & Brauneck 2009).

3.4 *The Façade type*

Traditionally, a building's skin has a shorter lifespan than its load bearing structure. The Façade type proceeding from it might thus be surprising. Although Leupen limits the permanent part to the building's front face, the entire skin could form a permanent enclosure. The lack of structural elements characterising the Façade type, provides a versatile space behind it or within the volume it encloses. Therefore, the skin should be self-supporting by for example truss structures. Leupen also states that the Façade type is limited to low-rise buildings. However, multi-story 'skins' are already realised, e.g. the four-story Crystalic 'greenhouse' office building in the Dutch city Leeuwarden.

Unlike the Base-building or Structural wall type, the Façade offers a collective or semi-public space that lacks compartmentalisation. Consequently, the building's transformable infill should be designed as sub-structures, preferably transformable. Suitable innovative property concepts might resemble leasing or rental contracts known from contemporary co-working offices.

To meet the occupant's needs, lightweight kit-of-parts systems can constitute space plan and services. Sub-structures can be suspended or stand independent from the skin, including their own access routes or alternatively offering space for sheared circulation. Due to the semi-public character of the inner space of the Façade and the temporariness of transformable sub-structures, management after construction becomes however essentially important for this type.

The Façade intermediates between public space, collective regulations and private interests. As a result, this typology owns the potential to gain cultural value and take advantage of the appreciation that is addressed to it. By the same token, the Façade screens the transformable building parts form public space and local planning regulations, overcoming one acknowledged obstacle for the implementation of transformable building in practice. For the same reason, this typology might be very useful to buildings whose façade already acquired cultural value.

3.5 *Structural service core type*

The fourth construction type is the Structural service core type. It proceeds from a base that is empty except from connections to the mains. Since these preconditions are the same in contemporary practice, it illustrates the opportunities of a traditional building to become transformable.

Although services have a technical lifespan of about 20 years and pipes and ducts have no load bearing capacity, their clustering in a vertical service core has the potential to constitute the frame for a transformable fit-out. In low-rise buildings, the service core is confined to a technical cell with enclosing walls and a platform. In the construction of multi-story buildings, services cores offer the overall stability. When they are made out of durable materials, they will offer a permanent but versatile frame and free the building from complicated technical services.

Similar to the Façade type, no compartmentalisation proceeds from the permanent part of the Structural service core type. This sets high requirements to the building's demountable structure, space plan and skin, but offers three dimensions of versatility and 'endless' extendibility. Consequently, the need for a well thought maintenance and management strategy is for this type as important as for the Base-building and Façade construction types.

A transformable load-bearing structure made of multi-purpose components can be assembled around the core. Thereafter it can be completed with floors, walls, and other layers. According to the Structural service core type, it is up to designer to create or select the most appropriate systems of compatible and demountable components, their hierarchy, scale, materialisation etcetera. Concluding, the Structural service core type stands the closest to the kit-of-part systems of all partially transformable construction types, enabling transformations that can be driven by technical, functional as well as economic and cultural change.

4 CONCLUSION

Given that the design strategy of transformability proved to be a sustainable approach to our built environment, regularly kit-of-parts systems are proposed because of their demountability and the compatibility of their constitutive components. Nevertheless, a broad literature study, searching for alternative approaches to deal with change within architectural design, detected multiple time-dependent aspects in addition to the key concepts of transformable building. Additionally, two case studies gave rise to the concept of partially transformable building.

The reappraisal of existing, but divergent partially transformable construction types resulted in a 'range' of such greater of lesser transformable types. The Base-building and the Structural wall, characterised by an inert building structure, the Façade, characterised by an inert building skin and the Structural service core type, proceeding from the technical services, were identified to have an important potential to anticipate change. Moreover, those types take into account the durability of the load bearing structure, the cultural value of the building's envelope, the effortless maintenance of a compartmentalised frame and the versatility of an open space plan. In those partially transformable buildings, the advantages of both traditional and transformable concepts are combined in a feasible way. For that reason, those partially transformable construction typologies should be considered in addition to kit-of-part systems when designing and researching our built environment.

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Condition monitoring and durability assessment of straw bale construction

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ABSTRACT: The use of straw bales in construction projects is still regarded by many as a novel technique with significant perceived risks. Barriers such as finance, certification and insurance all contribute to further restricting wider adoption. In all of the above cases long-term durability can be considered a prevalent concern. In particular construction industry concerns regarding long-term durability remain a notable barrier to mainstream adoption. Demonstrating the long-term durability credentials of straw bale construction can hence be considered one of the most significant ways of broadening the use straw bale construction within conventional construction markets. This paper presents a review of methodologies for condition monitoring, analysis, and interpretation of results for the short and longer-term assessment of straw bale buildings. The review is supported by research completed at the University of Bath and will help to inform and support future studies whilst also providing new insight into assessment criteria currently being developed.

1 INTRODUCTION

1.1 *Straw bale construction*

Contemporary use of straw bales in construction has increased significantly in recent years. Examples of straw bale buildings dating from the last twenty years can now be found in many countries around the world. These buildings are particularly numerous in the US, Canada and Europe (Fig. 1) though a notable number of buildings also exist across Japan, Australasia and China (Magwood et al. 2005, Holzhueter, K. &Itonga, K. 2010).

Figure 1. LILAC co-housing development in Leeds, UK

One of the oldest examples of straw bale building is commonly recognized as the Burke House in Nebraska, which was built in 1903 (King 2006). Now over a hundred years old, the building is still in existence today and is often held up as an example of the longevity offered by straw bale construction. Nonetheless,the observed success of the straw bale dwellings of Nebraska can be attributed to the largely dry climate that they are exposed to.

It has been suggested that some of the Nebraska buildings may have been built with baled rushes and not cereal crops, which could also have an influence on their durability. Figure 2 shows a bale recently taken from one of these buildings that was built in 1913. This bale was made using twisted wire, was in good visual condition, and is understood to be largely made up from rushes taken from the site of the building though a significant proportion of grasses were also visible.

Figure 2. Bale recently removed from Nebraska dwelling built in 1913

As straw bale building has moved beyond the relatively dry climates of Nebraska the range of climatic exposure has also grown. The result has been that independent precedent, testing and monitoring has been necessary to understand and demonstrate the durability of straw bale buildings in a wider range of environmental conditions. The significant global straw bale building stock now in existence suggests that concerns surrounding durability in a well detailed building are in the main unsubstantiated. However, whilst this is true for the majority of cases the building stock is relatively young and is still being deployed in climates where long-term precedent does not exist.

The implication of this is that construction industry concerns regarding long-term durability still pose a significant barrier to mainstream adoption. Demonstrating the long-term durability credentials of straw bale construction can hence be considered one of the most significant ways of increasing adoption in mainstream construction markets. Monitoring hygrothermal conditions within walls provides an evidence base from which long-term durability can be assessed. However, the use of suitable methods of analysis and interpretation of monitoring results are critical in ensuring such studies are reliably assessed.

1.2 *Methods of construction*

There are three main forms of straw bale construction; load bearing, frame infill and prefabricated panel systems. These forms of construction can be more simply categorised as load bearing and non-loadbearing (Goodhew et al. 2010) where the primary vertical load bearing structure is provided by the straw bales in the former. In the latter, timber structural elements are typically used and the straw bale is used to infill either an in-situ or prefabricated structural frame. Traditionally straw bale buildings would make use of a large roof overhang to protect the exterior walls from direct wetting by rain. However, as shown in Figure 1 some contemporary straw bale buildings are moving away from this traditional form of construction. In part this can be attributed to improved quality control arising from prefabrication of building elements. Experience gained from field tests and monitoring programs have also aided in understanding the performance of straw bale walls that do not rely on roof overhangs(Wall et al. 2012).

To aid in maintaining acceptable moisture levels within straw bale walls best practice requires that walls are built as a vapour permeable form of construction. This is normally achieved through the use of lime and earth based plasters and renders or through the use of suitable cellulose board systems. The term vapour-permeable relates to the manner in which a wall's constituent materials allow water vapour to diffuse through it. In the UK the internal environment of a building will often be warmer than the outside air and can thus also contain a higher concentration of water vapour. This higher concentration of water vapour will result from the elevated temperatures but also from the use and occupation of the internal space.

Given these conditions, a vapour pressure differential is setup across external walls between the internal and the external air. The opposite can occur where high levels of air conditioning are used in a hot climate. In the former case, this differential in vapour pressure causes the warm interior air to pass through the wall towards the exterior face. If a barrier to the movement of water vapour is included in the cool face of the wall then moisture can become trapped and at low temperatures condense to form liquid water. To prevent this occurring in walls using cellulose materials, vapour permeable materials are used through the full thickness of the wall. This allows movement of water vapour to occur between the internal and external air, which facilitates drying of plasters and elevated straw moisture levels associated with extreme rainfall or accidental wetting.

2 MOISTURE LEVELS IN STRAW BALES

2.1 *Avoiding the risk of degradation*

Drivers for increased moisture content in vapour permeable walls made with hygroscopic materials are summarised below. Focus is given to hygroscopic vapour permeable wall types though these drivers are common to all wall types and materials:

- Direct wetting from precipitation;
- Water vapour diffusion due to pressure differential across the wall;
- Rising moisture absorbed from the ground;
- Accidental exposure (e.g. flooding or a burst pipe).

Where excess moisture is present, factors that influence the long-term durability of wall materials often relate to microbial activity associated with fungal growth. Degradation of this form will occur under specific environmental conditionsinfluenced by the following factors (King 2006, Summers 2003):

- Availability of nutrients;
- Availability of oxygen;
- Temperature;
- Availability of moisture;
- Time periods of exposure.

Of the above factors, controlling moisture levels is considered the most important aspect of ensuring the success of straw bale construction. Robust detailing of a building will prevent the direct ingress of water from occurring. Thestraw bales that make up the wallsare commonly protected from direct wetting through the use of a vapour permeable lime based exterior render (Fig 1). This render is permeable to water vapour but absorption of moisture from precipitation sources is limited to the extent that the straw behind is not adversely affected.

Straw is a hygroscopic material, which means that it will adsorb water vapour from the air and absorb liquid water when exposed to a suitable source. Adsorption is the process by which water vapour molecules are held on the surface of a material through polar attraction. Materials that store water vapour in this way are termed hydrophilic. In the field of wood science, the point at which a material can store no more water vapour through adsorption is termed the fibre saturation point. At this point liquid water will begin to form within the pores of the material and this liquid moisture will be stored through capillary suction (Berry 2005). King (2006) notes that this behaviour is also applicable to straw though the moisture content for the fibre saturation point of straw is not given. It is at the fibre saturation point that decay of timber becomes a concern.

The moisture content of straw materials is typically expressed as a percentage of the dry mass of the material. Occasionally it is expressed on a wet basis and in this case the moisture content is given as a percentage of a material's wet mass prior to drying. For the purposes of this paper dry basis moisture content values will be used throughout unless noted otherwise. The dry mass of a sample is obtained through oven drying specimens at 105°C until stable mass readings are observed over a 24 hour period.

2.2 *Assessing risk*

Specifying limits for the acceptable moisture content of straw bales in construction is not straightforward. This is because the degradation of straw is influenced by many factors; perhaps most importantly the duration thatthe high moisture content is maintained but also what may be considered an acceptable or indeed unacceptable level of degradation. Lawrence (2009a) provides a concise reviewof recommended moisture content limits published in literature. It is recommended that straw bales not exceeding 14-15% moisture content are used for construction in the first instance but that moisture contents maintained at or above 25% will lead to degradation of the straw. However, whilst literature provides these guidelines the duration of exposure and subsequent severity of degradation are not developed further.

It is proposed in this paper that there may be two broad cases to consider when assessing the durability of straw bales in construction. The first is the risk associated with the germination and growth of mould arising fromelevated relative humidity levels. The second is the risk of serious decay resulting from the ingress of water or sustained levels of high humidity associated with the use of the building or the climate that it is built in. This decay would be recognised as causing detrimental damage to the building structure through significant breakdown of the straw.

An example of this is observed in the field of timber construction where blue stain fungi or surface mould can grow causing staining and discoloration of the timberwhen high relative humidity or moisture content allows. However, whilst the discoloration caused by the blue stain fungi affects the value of the timber it does not cause loss of mechanical strength (Ingold& Hudson 1993, TRADA 2004). Of greater concern in timber is the presence of wet or dry rot. These fungi occur when timber is maintained at moisture contents above 20% for a sustained period. They cause decay of the cellulose and lignin that forms the structure of the timber and are thus detrimental to its integrity. Dry-rot is particularly difficult to deal with as it is malignant due to its ability to translocate moisture from one location to another.

3 CONDITION MONITORING TECHNIQUES

3.1 *Measurement of straw moisture content*

There are several ways to monitor the moisture content of straw bales used in buildings:

- Electrical resistance measurements of timber blocks buried within the wall;
- Indirectly using measured %RH and temperature and determining equivalent straw moisture content;
- Direct measurement of the straw electrical resistance with a purpose built probe;
- Gravimetric determination of moisture content through removal and oven drying.

3.2 *Electric resistance of timber blocks*

Electrical resistance measurements of wood block and disc sensors buried within straw walls have been used in several studies (Goodhew, S. et al. 2004, Carfrae, J. et al. 2011, Wall, K. et al. 2012). The studies reported by Goodhew et al. (2004) and Carfrae et al. (2011) highlight the importance of calibrating the moisture content of the wood used to that of the straw being monitored.Goodhew et al. (2004) reported that the wooden discs used in their study allowed the measurement of straw moisture content to within ±2% (e.g. a range of 23-27% for a 25% straw moisture content). Carfrae et al. (2011) show that use of the timber species ramin improves this accuracy further to within 1.5%. However, the isotherms presented by Carfrae et al. (2011) also show that pine has a moisture content 6% lower than that of wheat straw at a relative humidity of approximately 93% and temperature of 23°C. This highlights the importance of calibrating wood sensors used with straw bale. To not do this risks significantly underestimating the moisture content of a straw bale wall and potentially not identifying elevated moisture levels prior to the onset of serious decay.

3.3 *Monitoring of hygrothermal conditions*

Relative humidity and temperature sensors are widely available and can be relatively inexpensive. However, these sensors will typically also need to be wired into a data logger which can be a limitation when installing them within a wall. It is possible to get wireless sensors which allow continuous, remote logging but these are significantly more expensive. Relative humidity and temperature data can be used to calculate an equivalent straw moisture content and in general this has shown to be reliable up to arelative humidity approaching 90% (Lawrence, M. et al. 2009a,b). However, beyond this point isotherms become asymptotic and thus an unreliable estimate of straw moisture content. A more appropriate method of using hygrothermal monitoring data may be to use it in its raw state and not to convert it to the moisture content equivalent. For example this could allow high relative humidity levels experienced in cold weather, where degradation risk is reduced to be more reliably assessed.

3.4 *Direct electric resistance measurements*

Manual moisture content readings can be taken using a stainless steel ‘balemaster’ probe produced by GE Ltd. This device is specifically calibrated for use with straw bales and is reported to be reliable to within +/- 0.5% for bales of average density (Carfrae et al. 2011).

3.5 *Gravimetric measurement*

The gravimetric measurement of straw moisture content through oven drying at 105°C and weighing of a specimen taken from a building is very accurate. However, it is also largely impractical and would only typically be done if there were good reason for opening up a straw bale wall.

4 MOULD GROWTH

4.1 *Using hygrothermal data for assessment*

In order to assess the risk of mould growth in a straw bale wall it is necessary to have knowledge of both the prevailing temperature and relative humidity conditions. This allows an understanding of the likelihood and severity of mould growth to be determined. For instance conditions of 90% RH and 5°C would not be of significant concern whilst the same relative humidity at 20°C would suggest a high risk of mould spore germination and growth.

A significant amount of research has been completed at the Fraunhofer Institute of Building Physics to characterise the mould resistance of many different building materials (Hofbauer2005, Hofbauer, et al. 2008, Sedlbauer et al. 2011). A specialist test setup was developed to allow specimens to be subjected to a range of climatic conditions through varying temperature and relative air humidity. The findings of these tests were subsequently presented using a graphical ‘isopleth’ system. This isopleth system provides a traffic-light guide to climatic conditions that can support mould growth. A green area indicates no risk of mould growth and yellow indicates ‘attention’ as mould growth is possible. The red zone is to be avoided as mould growth is likely to occur when the material is held under these conditions.

The experimental test setup was initially used for investigating mould growth on the surface of mineral based materials used as internal and external wall finishes (Hofbauer 2005). The specimens measured 5 x 5 x 2.5 cm and were sterilised prior to testing using gamma radiation. Known fungi were subsequently used to inoculate an area of the specimen. Visual measurements of mould growth were conducted for 100 days after inoculation of the specimens. After this point germination of the inoculated spores was not expected (Sedlbauer et al. 2011).

Visual monitoring of mould growth on the specimens was recorded by taking photographs, which allows comparison to be drawn over time. The results of the study allowed climatic conditions to be determined that will support mould growth over the 100 day period of exposure. However, although the isopleth traffic light provides a visual guide to exposure under steady state conditions for 100 days, it is noted by Hofbauer et al. (2008) that initial measurements under dynamic conditions indicate that resistance against mould can be influenced and controlled by climatic changes.

4.2 *Case study*

An example of the isopleth assessment method is shown below in Figure 3 for monthly average relative humidity and temperature data. The data were recorded from 2009 to 2012 from an un-heated exposure facility in the south west of England. The location of the sensors was at the base of the middle panel shown in Figure 4. This panel had 30-40mm thick lime based render applied to the interior and exterior face of the straw bales and faces due south-west, which is the prevailing wind direction.

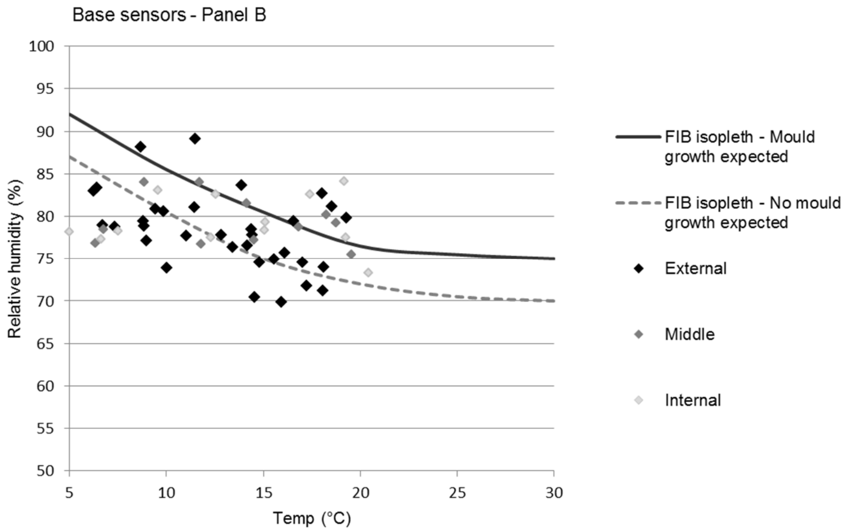

Figure 3. Monthly average data plotted with isopleth boundaries

Figure 4.Exposure test facility in south-west England

It is apparent that a significant number of the data points fall above the red threshold for mould growth. It would therefore be expected that a certain level of visual degradation would have occurred within the base of this panel. In order to investigate this further a visual inspection of the straw was made by removing a 150mm diameter core of render at the base of the external face of the panel. This core is shown in Figure 5. It was apparent from inspection of the straw that serious degradation of the straw had not occurred within the base of the panel and the fixity of the straw to the render remained. Some discolouration of the straw was however apparent which would be associated with previous mould growth. At the time of inspection (November 2012) the gravimetric moisture content of the straw immediately behind the render was 28.4% on a dry basis. Based upon the literature this relatively high moisture content would also suggest that deterioration of the straw would be likely. Nonetheless active signs of decay were not evident beyond a slight dampness to the straw immediately behind the render.

Figure 5. External render core removed from exposure test facility

4.3 *Long term performance*

The findings from the straw bale exposure facility raise the question of how the risk of straw degradation can be reliably assessed without being overly conservative. There is a need for the means to assess hygrothermal monitoring data for both transient mould risk and serious degradation or decay. The results shown in Figure 3 suggest that mould growth will have occurred at certain periods within the panel in question and this is supported by discoloration of the straw. However, long-term decay was not apparent upon removal of the render. The high moisture content recorded at the time of render removal also suggests that mould growth should have been present at the time of inspection though this was not observed. This suggests that in the long-term mould growth may be arrested within a wall due to the restriction of a viable nutrient supply following previous colonisation by fungi. This hypothesis is supported by on-going research at the University of Bath but is beyond the scope of this paper.

Whilst the hypothesis that straw may be able to withstand relatively high transient moisture contents without suffering serious decay is encouraging it raises some interesting questions. Firstly if the conditions for mould growth are met within a new wall made with fresh straw it is possible that a certain level of mould growth could occur. If this is the caseis this likely to raise any health concerns, perceived or otherwise? Secondly, if elevated transient moisture levels are not of concern in terms of serious decay of the straw how long can they be maintained before serious decay does occur? It is feasible that like timber the risk of colonization by serious decay fungi such as dry rot is only an issue when unfavourable conditions are maintained in the long term.

5 CONCLUSIONS

Current study at the University of Bath is focused on understanding the resilience of straw to transient exposure to high relative humidity conditions. An isopleth as set out by Sedlbauer et al. (2011) is compared with monitoring results from an exposure test facility. The isopleth was derived for fresh wheat straw. The work suggests that mould growth as defined by the Fraunhofer Institute isopleth may not be a long-term concern in terms of decay of straw bale walls. However, there may be associated concerns surrounding health if a significant growth of mould occurs. It is considered that an extension of the isopleth is necessary to include less conservative boundaries that address the time of exposure and the risk of serious decay above that of mould growth. This would allow monitoring results to be interpreted more reliably and avoid over conservative assessment.

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Innovative Sustainable Architecture: constructive processes and materials

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ABSTRACT: The current consumption rate of fossil fuels and natural resources in the construction activities is unsustainable. Actually this activity consumes resources well above natural systems restoration capacity, being responsible for 30% of world's carbon emissions. The efforts to increase sustainability using energy from renewable resources should include innovation in the construction methods and the valorisation of waste through its reuse or transformation which has obvious economic and environmental advantages, allowing savings of natural and material resources. The present work aims to evidence the contribution that existent materials and constructive techniques can provide for sustainable development in the construction sector, supporting innovative ad eco-friendly techniques and processes that reduce Environmental Impact, identifying the reasoning for preservation of the natural resources and endorsing the use of renewable energies. The outcome of this research presents the results related with sustainable architectural techniques and processes, using "environmentally friendly" materials, and analyses its applicability in a physical architectural model developed in this work. With the aim of attaining a sustainable architecture, an evaluation is proposed at the different life cycle stages, as the CO_2 emissions calculation and the analysis of the network supplied energy savings provided by the renewable energies used, as well as the feasibility of material's recycling at the end of its useful life.

1 INTRODUCTION

Currently the construction sector is an activity that consumes natural resources quite beyond their restoration capacity, thus causing severe damages to the environment. The pressure for speedy building's construction, including at project level, the initial costs down-sizing, the risk of legal responsibility or even some cultural perceptions, are not favorable to changing practices or mentalities (Santos, 2010). As we know, humanity has been consuming resources above their restocking capacities and the restoration capacity of the natural systems.

Human society will always depend on the critical balance keeping, between three key variables: population, natural resources and environment. With the increase of population and the high level of urbanization along the centuries, construction sector trends have become unbearable, and the buildings have consumed the main share of the material resources, approximately 3.000 million of tones each year (Torgal et al., 2010). Approaching these main themes (resources, materials, construction and wastes) the present work intends to spread awareness and responsiveness among agents, stakeholders, sellers, buyers, constructors or dealers. A sustainability construction process should consider an adequate balance between the capacity rate that environment has to provide resources and absorb waste, without depletion and minimizing environmental impacts, and the requests placed by Humanity. Subsequently, a building could be considered as sustainable when (Gil, 2000):

- Consumes the less possible quantity of energy during its life cycle;

- Uses renewable, reused or recycled materials;
- Generates the slightest quantity of waste and pollution;
- Satisfies the needs of its users, in the present and the future.

2 SUSTAINABLE CONSTRUCTION

Sustainable architecture has emerged through a variety of concepts since the beginning of 20th century: Low-energy, Solar design, Bioclimatic and Passive, Ecological, Green, Self-sufficient and Near Zero-energy building (nZEB). The variations among these concepts are based mostly on the context and the time they occurred. Among the whole package of concepts that sustainable architecture can be expressed for, the bioclimatic is the most extensive one. The concept of bioclimatic architecture has been attributed to a type of architecture which is adapted to the environment and takes into account the visual impact and disruption it causes to nature. Inside this concept is the nZEB, which also concerns about the use of individual supply systems (water, sewage and electricity) or the use of renewable energies in order to keep them "low-emissions". In short, the main concepts to achieve a sustainable architecture, and which I try to incorporate as much as possible in the design of the Eco-house are, as follow:

Site Planning: It starts with the site analysis, where issues of particular concern are climate, landscape, sunlight and solar gain, daylight and views, wind, noise and air quality. Bioclimatic design capitalizes on the characteristics of the site in order to minimize the energy needs of the building and to create a more comfortable environment (thermal, acoustic, natural light) adapted to the ways and lifestyles of the inhabitants. In addition, special attention is dedicated to respect the existing landscape and the building's integration in it;

Natural Ventilation: Ventilation which is driven by wind or by air flows resulting from heat transference between the interior and the exterior, depending on the air pressure and temperature differences. The wind could always influence, in an active and meaningful way, the energetic performance of the building;

Passive Strategies: In a building conception design, when the right climate strategies are used, the thermal comfort conditions are closer to be achieved with minimum energy consumption. The adoption of these strategies improves the building performance in terms of interior thermal comfort as they are distribution agents of the heat-energy by natural transference processes. In cooling passive systems the purpose is to get advantage of cold sources. These strategies should be developed concerning the solar orientation, natural ventilation, the right size of the portholes and the activity of each space. Furthermore we can use the solar energy to complement active heating systems without compromising the emission of gases and pollutants. We have to keep in mind that passive architecture and its thermal and comfort conditions are often successfully provided by the user himself. He should keep the system active, changing all the needed features to maintain the air quality and interior environmental conditions;

Reusing of Water: The increasing demand for water can be met either by intensifying the capacity of supply (e.g. by building new reservoirs), by reducing the consumption of water or by reusing water wherever possible. Reusing water has the main objective of creation of new supply sources to overcome population growth, helping to decrease the Environmental impact;

Renewable Energies: The management and transformation of natural resources formulate a massive and central theme in seeking for sustainability. An intensive exploitation of natural resources beyond their capacity of renovation causes environmental problems. "Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the Earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources" (EIA).

3 IMPACT OF CONSTRUCTION MATERIALS

A comprehensive knowledge of the importance of construction materials in the sustainable context should involve a full understanding of which have been the environmental impacts caused by raw material extraction and their production. In this context one of the most pressing environmental questions relies on the possibility of non-renewable raw materials exhaustion.

Besides the remarkable question concerning the possibility of non-renewable raw materials depletion and the associated environmental impact due to their extraction, there are others that should be considered in the context of sustainable construction materials (Santos, 2010). Their choice should privilege the materials, (1) nontoxic; (2) with low embodied-energy; (3) recyclable; (4) durable; (5) which could allow the reuse and recover of wastes; (6) that provide from renewable sources; (7) associated to low emissions of gases and toxicities; (8) and the ones where an analysis of their Life Cycle is done.

The range of impacts of buildings on the environment is diverse. Problems which result from construction – related processes, such as global warming, ozone depletion, loss of natural habitat and biodiversity, soil erosion and release of toxic pollutants are now well known.

3.1 *Life Cycle Analysis*

To establish the true environmental impact of a building the analysis may be carried out in a way that reflects the relative importance of different building elements and processes, and the priorities for reducing environmental impacts. This is called Life Cycle Analysis (LCA, also known as Life Cycle Assessment and cradle-to-grave analysis). A LCA is based on ISO 14040 and it consists in a technique to assess environmental impacts associated with all the stages of a product's life. LCA can help avoid a slight outlook on environmental concerns by compiling and evaluating the potential impacts of products and materials associated with identified inputs and environmental releases; interpreting the results to help making a more knowledgeable decision.

In life cycle assessment, an environmental product declaration (EPD) is a standardized way of quantifying the environmental impact of a product or system. Declarations include information on the environmental impact of raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water and waste generation. Product and company information is also included. The EPD project contributes to the implementation of an LCA approach and eco-design of the products.

4 PROPOSAL: ECO-HOUSE

This project is about designing a passive and zero-energy house in Portugal containing climate-optimized structure. The solution should be within the requirements of a Net Zero-Energy Building (NZEB), but also look to obtain a holistic sustainable elucidation. The house would be adapted to common sense and world reality, which means that it was chosen to articulate functionality, aesthetical parameters and passive strategies. It would have an ecological performance with a balance of the user’s needs, achieving the comfort and respecting its function.

In order to analyse the conditions of the site it is important that a precise place is established. The Eco-house will be developed for a Mediterranean climate, specifically in the suburbs of Lisbon, Portugal, once there is more pollution and density which make the temperatures increase (about 2ºC) and surrounding buildings change wind and solar conditions. In Portugal the availability of the solar resource is high; standing well above the European average (the average annual number of hours of sunshine in Portugal is approximately 2500 hours).

4.1 *Design Strategies*

4.1.1 *Modular System*

Modular housing construction allows a variety of alternatives and design possibilities, offering a wide range of options to customize the house. It is possible to modify or upgrade the construction specifications, designing different floor plans and choosing, for instance, the strategy of the façades. Reducing costs is implicit in this type of construction due to the time saving and process easiness, although it is not the aim of this work to reflect on this question. Thus, modular home construction is more environmentally friendly than its site-built counterpart relating to the wastes management: all the excess construction materials are able to be recycled in site. Thus, the main idea for the Eco-house is to be built by a timber modular system (2.10m * 4.00 m), which will be the structure of the house. The arrangement of the plan is made according to the needs specified for this project by coupling the modules.

4.1.2 *Passive Cooling system*

The natural ventilation strategy relies on two different approaches: natural ventilation achieved by the windows and allowing the natural movement of the wind; and a Passive Cooling system using buried pipes. This system will be provided by the air entering the house through buried pipes using the important cooling potential in the soil (cold source): the outside air is insufflate inside the house by natural or forced convection using small fans. With this purpose 20 tubes were placed in cement pipes – with a diameter of 20 cm – constituting the heat exchanger. It should be noticed that pipes were chosen based on the material's high thermal conductivity[1] to enhance heat exchanges. The air entrance is made from a feeding well about 15 meters away from the house. When inside the house the pipes don't need to promote heat exchanges anymore so the tubes are metallic. Once again, the user's behaviour is crucial to the well function and performance of this passive system.

4.1.3 *Renewable energies*

The strategies which rely on the renewable energy resources used in the Eco-house are the Photovoltaic system (PVs) and the Solar Thermal collectors placed on roof of the Eco-hand and transferring the heat energy collected into the tank by forced circulation of the working fluid between collector and the tank. Based on the information of electrical energy needs, the Photovoltaic cells installed on the Eco-house have an overall area of 30 m^2 which means a monthly produce of 375 kWh of electricity.

4.1.4 *Reusing water*

It is crucial to have a saving system for the house in order to store the rainwater allowing its reuse. With this aim it is placed a tank with a capacity for 25 120 litres outside the house where the rainwater gets in by the roof pipes - gutters. The water is kept in the tank until it is necessary. In summer, or even in some winter days, in case there is no stored water the house will be supplied by the public network. Before entering the house the water will pass through a Bio-Disk purification system. The system is installed near the tank and it will recycle the rain water, purifying it and allowing its use inside the house. Despite purification the water may not be ready to drink as potable so it is advisable an extra caution to the occupants. When inside the house the water will be kept in a cylinder with capacity for 300 litres capacity where it will be heated by solar thermal energy.

4.2 *Design Outcome*

Following the analysis of the design strategies for the eco-house it is presented the final result (figure 1): a geometrical and unpretentious volume with the main glazing façade towards south/south-east which confers transparency and connection with the surrounding environment. The white façades confer lightness to the structure and the tile roof gives the house a traditional and typical appearance.

Figure 1: 3D model of the Eco-house

4.3 *Performance - Life Cycle Stages*

The aim of the first analysis is to evaluate the amount of CO2 released to the atmosphere in the manufacture and construction phase in order to confirm their environmental efficiency. Currently, the purpose is to analyze how much CO2 is released, correlating the emissions values for manufacture and construction process excluding transportation, with the material mass needed for built the Eco-house.

Another important consideration is the comparison term in order to evidence the positive results and success of all the strategies adopted. A study concerning the Sustainability and Life Cycle Analysis in Residence Buildings (CWC – Canada Wood Council) analyzed three different construction types of a typical house (wood, steel and concrete) with the same assumptions for the thermal insulations and the constructive details. The Global Warming Potential for the wood construction is 60 kg CO2 and for concrete (the most extreme among the three case-studies) is nearby 96 kgCO2. Concerning the Eco-house calculations, the results are shown in table 1 where it is perceptible the reducing of CO2 emissions confronting with the sustainable residential house proposed by CWC.

In order to confirm the efficiency of the renewable energies systems used in the Eco-house, I propose a second analysis of Eco-house performance, concerning the energy savings during 20 years. In Portugal the average electrical consumption is nearby 4.000 kWh/year (ADENE, 2010), including electrical heating (approx. 800 kWh/year). In 2011, electrical energy produced in Portugal has been generated from renewable energies (46%), natural gas (28%), coal (18%) and other thermal sources (8%) (REN, 2011). Following this chain of thought, table 3 shows the proportions between the amount of CO_2 release into the atmosphere (WEC, 2004), provided from each one of the electrical production source, and the percentage (%) of their use.

For the forward comparison it will be assumed that electrical energy needs are supplied by electrical production from the grid, instead of using the PVs. Taking into consideration that the Eco-house consumes 4200 kWh/year, it is possible to observe that the electrical needs using renewable energies (PV system) will release 210 kgCO_2/year (4200 kWh/year x 5 KgCO2/100kWh); but, if the electricity was provided by the national grid it will emit approx. 1 449 kgCO_2/year (4200 kWh/year x 34.5 KgCO2/100kWh). Concerning hot water consumption, the Eco-house has its own production by the Thermal Solar Collectors system, with a typically output between 1000 and 2500 kWh/year (sub-chapter 4.4.6.2). This means that the energy production will be sufficient to supply the user’s needs (900 kWh/year by the information illustrated in figure 4.21), even if it do not perform at 100% efficiency. So, the collector system will avoid that the national electrical network had to provide that amount of energy, 900 kWh/year. This corresponds to a saving of 310.5 kgCO_2/year. The cooling consumption has an average value in the typical house of 200 kWh/year, and once it is not used in the Eco-house due to the

Passive Cooling System projected, it means a saving of 69.0 $kgCO_2$/year (200 kWh/year x 34.5 $KgCO_2$/100kWh).

Table 1: Manufacture and Construction stages, and related CO2 emissions, excl. transportation

	Material	Weight [kg]	CO2 emissions [kg/kg] Source: D.J Gielen, 1997	TOTAL [kgCO2]
Structure	Timber [module]	15.074,40	0,3	4.522,30
	Timber [truss]	3.326,40	0,3	997,9
External Wall	Beech wood	2.457,00	0,4	982,8
	Cork	382,3	0	0
	Rock wool [1]	236,9	1,1	260,6
	OSB	2.124,00	0,3	637,2
Internal Wall	Beech wood	2.702,70	0,4	1.081,10
	Cork	294,5	0	0
	OSB	2.454,00	0,3	736,2
Roof	Rock wool [1]	388,8	1,1	427,7
	PET, recycled	4.665,60	1	4.665,60
	Tile (ceramic)	3.110,40	0,15	466,6
	OSB	3.456,00	0,3	1.036,80
Floor	Concrete	24.192,00	0,85	20.563,20
	Mortar [2]	2.721,60	0,3	816,5
	Rock wool [1]	340,2	1,1	374,2
	Quick step	5.140,80	0,4	2.056,30
	Betuminous	1.512,00	0,3	453,6
Windows	Glass	4.009,50	0,7	2.806,70
	Aluminium, Recycled [frame]	4.276,80	1	4.276,80
Outside Door	Dark Timber	432	0,4	172,8
[1] Flury, 2012				47.334,80
[2] Source: Limeco Ltd HyperLime				

Table 2: Share of Electrical Production Sources in Portugal, year 2011

Resource	$kgCO_2$/100kWh	Electricity origin by source (%)	Weighted emissions
Coal	90	18	16,2
Natural Gas	40	28	11,2
Renewable	5	46	2,3
Other	60	8	4,8
			34,5 $kgCO_2$/100kWh

The calculations show that the Eco-house, for avoiding electrical consumption from the electrical national grid, will save in a period of 20 years approx. 24 780 $kgCO_2$ due to PVs system; 6 210 $kgCO_2$ due to the use of Thermal Solar Collectors, and plus 1 380 $kgCO_2$ resulting from the Passive Cooling system.

Finally, to ensure that the materials chosen for the Eco-house are reusable and recyclable (which means they have to be easily deconstructed), at the end of their useful life, the following figure illustrates the quantity of recyclable materials existents in the Eco-house, being 82% able to recycle.

4.4 *BREEAM Certification*

BREEAM is “the world's leading environmental assessment method to assess new, existing buildings and community scale development (BRE Global). By BREEAM’s website (www.bre.com) is it possible to access the information needed to the evaluation of constructive solutions chosen for the Eco-house, which are not exactly the same as BREEAM suggested solutions, so I had to choose the most similar ones to evaluate the ranking. The results for the possible Green Certification of the Eco-house are shown on table 3.

Table 3: Possible Ranking for the Green Certification. Adapted from BREEAM

	Category	Element type	Rating
Ground Floor Construction	Suspended timber	OSB/3 decking on timber joists with insulation, over 100mm oversite concrete	A
Roof Construction	Pitched roof timber	Timber trussed rafters and joists with insulation, OSB/3 deck, breather membrane, standing seam organic coated steel sheet.	A+
External Wall Construction	Rendered or Fairfaced Blockwork	Fair face solid blockwork outer leaf, insulation, timber frame, vapour control layer, plasterboard on battens, paint	A+
Internal Wall	Framed partitions	Timber stud, OSB/3 facing, paint	A
Insulation	CorkBoard	Corkboard insulation - density 120kg/m³	A
	Rockwool	Stone wool insulation - density 45 kg/m³	A+

5 CONCLUSIONS

This work analyses and deepens the topic of sustainability and environmental concepts applied in the construction sector. It aims to demonstrate how it is possible to achieve a sustainable use of natural resources, contributing to their preservation and reducing the environmental impacts. Also it highlights the overwhelming importance of this world's issue, as well as gives a detailed explanation of how the constructive sector can play an important role to fulfill this goal. Although technological progress is in a continuous and steep growth and we should follow and make the most profit from this development, it is of crucial importance to keep in mind the simple, natural and inherent ideas and concepts of sustainable practice. Actually we must avoid being trapped by the trends of technological evolution, which are basically oriented towards speedy gains in competitiveness, namely by cost reductions in non-sustainable materials incorporated in the construction process, no matter their scarcity in nature or their embodied energy and, consequently the related GHG emissions.

Reaching the end of the study I consider that the main goals proposed were achieved, including the architectural model developed which proves and summarizes the ideas presented and discussed throughout the text as: evidence how a rigorous selection of construction materials can give a positive and valuable contribution to a sustainable practice by analysing their main environmental characteristics, such as embodied energy and CO2 emissions; identify the deconstruction concept as a way for preserving the materials life and signal the importance of reusing and recycling processes and; last but not the least, validate the use of renewable energies in an architectural design, matters which should be integrated through the initial decisions.

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Chapter 11

LCA of sustainable materials and technologies

Carbon footprint impact of balcony glazing in Nordic climate

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ABSTRACT: By the end of the year 2012 approximately 60 000 block of flats were built in Finland. Most of the buildings are pre-cast concrete structured with extended concrete balconies. Since the middle of 1980s these balconies are typically equipped with balcony glazing.
This article discusses the Finnish-made balcony glazing carbon footprint impact and life-cycle emissions compensation period with different levels of recycling when the products are installed in the 1970s pre-cast concrete blocks of flats in Finland and Canada. The calculation was carried out the GaBi 4.0 software by using the Business to Consumer (B2C) life cycle.
According to calculations, the carbon dioxide emissions for commonly used balcony glazing solutions will range from 170 to 250 kg CO_2 in Finland and from 180 to 260 kg CO_2 in Canada. Life-cycle emissions will be compensated in 1.1–9.3 years in the Finland installation cases and in 1.2–9.7 years in the Canada installation cases. The average compensation period for emissions is 3.3 years in Finland and 3.5 years in Canada.

1 INTRODUCTION

1.1 *On Finnish building stock and balcony structures*

Due to the massive need for residential buildings and the rapid development of prefabrication techniques of precast concrete panels in the 1960s and ‘70s, concrete soon became the dominant material of facades and balconies in multi-storey residential and office buildings in Finland (Mäkiö et a. 1994).Since the 1960s a total of approximately 44 million sqm of concrete panel facades as well as more than 900 000 concrete balconies have been built in Finland (Vainio et al. 2005). In fact, more than 60% of the Finnish building stock has been built in the 1960s or later. Compared to the rest of Europe, the Finnish building stock is rather young. By the end of the year 2012 approximately 60 000 apartment buildings were built in Finland. In those buildings there are a total of 1.2 million apartments in Finland (Statistics Finland 2011) which is a lot compared to the Finnish population of 5.4 million.

All prefabricated concrete structures in Finland are based on the Concrete Element System (BES 1969). This open system defines, for instance, recommended dimensions of floor-to-floor height and types of prefabricated elements. The system allows, in principle, the use of prefabricated elements made by any manufacturer in any multi-storey building.

The most common balcony type in Finland from the late 1960s until today has consisted of a floor slab, side panels and a parapet panel of precast concrete, see Figure 1. These stacked balconies have their own foundations, and the whole stack is connected to the building frame only to brace it against horizontal loads. All structural members of a precast balcony are load-bearing.

Figure 1. Typical Finnish concrete balcony with balcony glazing.

The durability properties of concrete, like material properties related to frost resistance of concrete or cover depths of reinforcement, very rarely fulfil the requirements of Finnish national building codes (Lahdensivu et al. 2013). Due to this Concrete balconies have been repaired extensively in Finland since the early 1990s. In most cases pats repairs with protective coatings has been the most applicable repair method. In many cases balcony glazing was installed to decrease stress level of structure caused by driving rain.

In the beginning the reason for installation of glazing in Finland was purely to extend the living area and to increase the usability of the balcony space. After a few years experience, in the late 1980s, it was nevertheless noticed that the surfaces inside the glazed balconies remained in better shape and the space a couple of degrees warmer than in traditional open balconies. (Mattila 2007).

The study made in Tampere University of Technology showed that balcony glazing systems protect both the structures and the coating materials; corrosion rate is decreased remarkably and frost weathering stopped completely. The temperature on a glazed balcony remains higher all year, and this dries the concrete structures. (Mattila 2007 and Mattila 2003). In further research profound testing and monitoring showed that 3.4-10.4 % savings in energy consumption of apartments can be achieved in Finnish outdoor climate (Hilliaho 2010).

1.2 *Typical glazing structures in Finland*

According to manufacturers the most commonly used balcony glazing structure in Finland is frameless and single glazed balcony glazing, see Figure 1. The glazing typically consists of 5-6 balcony glass panes, which can be opened and closed as necessary using simple sliding and opening mechanisms. The system is characterized by transparent float glass panes, non-insulated aluminum profiles and relatively non-tight structure. The glass panel system is fit in with the balcony structure with an edge seal, mountings and adjustment profiles. The flashing used for water guidance is made of plastic-coated steel sheet. The glass panels are made of 6 mm thick tempered float glass and there are 2-3 mm gaps between the glass panes for balcony ventilation. (Lumon Oy 2010).

1.3 *Objective*

This article discusses the Finnish-made balcony glazing carbon footprint impact and life-cycle emissions compensation period with different levels of recycling when the products are installed in the 1970s pre-cast concrete blocks of flats in Finland and Canada. The variables in the four calculation cases are the recycling degree and the distance from the plant to the installation site. It is also evaluated balcony glazing effect to decreasing total CO_2 emissions of building due to energy and emission saving effects. All calculation cases was carried out by using PE International`s GaBi 4.0 software (Gabi 4 2013) and GaBi databases 2006 (GaBi 2013).

2 RESEARCH MATERIAL AND METHODS

The research material consists of energy consumption simulations of apartment building and carbon footprint calculations of balcony glazing.

2.1 *IDA-ICE simulations related to energy consumption*

The starting point in the carbon footprint calculation was the balcony glazing system in a high-rise building located in Tampere (61°29′53″N, 023°45′39″E), Finland. The building is a 1+6 storey apartment building completed in 1979, with 3 staircases and 54 apartments. The building is connected to the district heating network and ventilated by mechanized exhaust ventilation system. At the site, facade renovation works were carried out in 2004, in which connection the windows and doors were renewed and facades repainted. In the same connection, the condition of HVAC systems was checked and the ventilation system and radiator network were balanced. The exhaust ventilation machine itself remained the same, but was equipped with modern timer control.

In this high rise building, the energy saving effects of balcony glazing was investigated with the help of field research and computer simulations during different seasons in-between July 2009 and June 2010. The field research was carried out for evaluation energy efficiency impact of balcony glazing in practice and for the calibration of the IDA Indoor Climate and Energy (IDA-ICE) 4.0 software model. Software based on IDA simulation environment originally developed by the Division of Building Services Engineering at the Royal Institute of Technology (KTH), and the Swedish Institute of Applied Mathematics, ITM. The mathematical models of the IDA ICE have been developed at the Royal Institute of Technology in Stockholm and at the Helsinki University of Technology. IDA simulation environment has been under development since the 80s and IDA-ICE since the late 90s. (Kalamees 2004 and Sahlin et al. 2005)

After model calibration, variation was carried out for estimating the influence of balcony type (integrated vs. extracted balcony), orientation, thermal insulation, building location, and balcony airtightness on the energy savings achievable in the building by balcony glazing. In addition to this, it was determined to what extent energy efficiency impacts of glazed balconies can be improved by intake of the building’s supply air in a preheated state from the balconies. Calculations were made to examine how glazed balconies behave under Finnish outdoor climate.

2.2 *Carbon footprint calculations*

The calculation was carried out by using the Business to Consumer (B2C) life cycle. The variables in the calculation are the recycling degree and the distance from the plant to the installation site. Other initial data are the same in each calculation case. The recycling degree and the distance from the plant to the installation site were selected as variables due to their large variation. The calculation considers the extreme limits of both calculation variables. The calculation results in an estimate of the variation and payback periods of carbon dioxide emissions in Finland and Canada. The payback period refers to the length of time required for these emission savings due to the energy savings to equal the emissions generated during the balcony glazing's manufacturing, installation, maintenance and recycling. After the payback period, the net emissions caused by balcony glazing will change into negative figures. The key input data for calculation is given in Table 1.

According to information given by balcony glazing manufacturer, a total of 60–98% of materials will be recycled in an optimal situation. This fact was taken as the second starting point for the calculation. According to calculations, all use of recycled materials is expected to belong to materials recovery. The materials recovery denotes that material properties will be reused; i.e. glass is made of glass. To include the impact of the recycling degree, the calculation contains a pessimistic calculation case in which a total of 70–80% of materials was expected to be carried to the landfill site and waste incineration plant. The recycling degree of materials is shown in

Table 2.

Table 1. The delivery content of the balcony glazing system for case building.

	Material	Weight kg	Total weight kg
Balcony glazing	Glass panels	87.2	
	Aluminum profiles	16.5	
	Flashings	5.0	108.7
Package	Disposable pallet	11.0	
	Plastics	5.0	
	Corrugated board	2.0	18.0
Offcut of materials	Glass	13.0	
	Aluminum profiles	2.5	
	Flashings	1.0	16.5

Table 2. The recycling degrees of materials

Material	Recycling degree	
	Optimal scenario	Pessimistic scenario
Glass	95 %	32 %
Aluminum profiles	80 %	26 %
Flashing	97 %	32 %
Plastic	70 %	24 %
Cardboard	60 %	20 %

The calculation was carried out with the GaBI 4.0 software developed by PE International. The GaBi Extended Database was used as the materials database. The EDIP(Environmental Development of Industrial Products) 2003 method was used as an impact assessment method and standards ISO 14044 and 14040 as calculation standards. As the research was recognized that there was not the last versions of the program and the database in use. Differences in the newer versions, however, was considered to be so small that updates not seen the need for this stage of the investigation. The results have been shown in the form of carbon dioxide equivalents.

The four different calculation cases are:

1) A normal case in Finland with assumed 60–97% recycling degrees.
2) A normal case in Finland with recycling degrees diminished to a third.
3) A case in Canada with assumed 60–97% recycling degrees.
4) A case in Canada with recycling degrees diminished to a third.

3 RESULTS AND DISCUSSION

3.1 *Balcony glazing's effect on heating energy savings*

Under Finnish outdoor climate, the heating energy savings achieved through balcony glazing in an 80 m^2 apartment varied between 3.4% (1.9 kWh/m^2/a) and 10.7 % (10.4 kWh/m^2/a), depending on calculation case. Balcony glazing was the most useful in case of some Helsinki buildings constructed in the 1970s, with balconies oriented southward and supply air intake arranged through balcony. Respectively, energy savings were the smallest in modern (constructed in 2010) buildings located in Sodankylä, with glazed balconies oriented eastward and supply air intake arranged from outside the balcony. The average energy saved under Finnish outdoor climate amounted to 5.9 % (4.4 kWh/m^2/a). Intake of supply ventilation air through the balcony proved to be the most important factor influencing energy savings. The balcony type and building orientation also exerted significant influence on the energy savings achieved. On the other hand, the energy savings-related impact of building location, insulation level and balcony airtightness did not prove to be as significant (Hilliaho 2010).

3.2 *Carbon footprint of balcony glazing*

The calculation results will be presented case by case in this section. The Table 3 shows carbon dioxide emissions in calculation case 1 and 2 by emission source.

In Finland most of the emissions are generated by the reproduction of recycled materials (62.5 kg CO_2-Equiv. or 39%) in better recycling case. Another major cause of emissions is the manufacturing process of the product at balcony glazing manufacturing plant (52.6 kg CO_2-Equiv. or 32%). Moreover, the carbon dioxide emissions caused by the landfill site and energy waste are significant (27.7 kg CO_2-Equiv. or 17%). Other causes of emissions account for quite a minor part of total emissions (total 12%) in accordance with Table 3.

Table 3. Carbon footprint of balcony glazing in Finland with optimal recycling and worst recycling.

The cause of emission	A normal case in Finland with assumed 70-97% recycling degree	A normal case in Finland with recycling degree diminished to a third
	CO_2-Equiv	CO_2-Equiv
Transport by rail	0,0	0,0
Landfill site and energy waste	27,7	81,9
Transport by road	4,8	5,3
Transport by ship	0,1	1,5
Lumon Oy`s balcony glazing plant	52,6	52,6
Recycling and reproduction of material	62,5	26,7
Pallet	5,5	5,5
Flashing (steel plate)	2,4	8,8
Polystyrene (packing material)	3,3	8,4
Aluminum profile	0,5	11,7
Glass	3,3	46,2
Corrugated board (packing material)	0,3	0,6
Total	162,9	249,1

Comparison of better recycling case and worse recycling case the results shows that the absolute values of carbon dioxide emissions will change remarkably for glass, landfill site waste and energy waste in particular, if the recycling degree is diminished. And the absolute value of landfill site waste will be dominant when recycling degree drops to a third. The results show also that the recycling of glass in particular is recommendable because of great increase of emissions.

In Canada (cases 3 and 4) the amount of emissions is very similar to the corresponding cases in Finland. The most significant carbon dioxide emissions are caused by recycling and reproduction (62.5 kg CO_2-Equiv. or 36 %) and the manufacture of the product at balcony glazing manufacturers plant (62.5 kg CO_2-Equiv. or 30 %) in better recycling case. The most important difference between calculation case 1 and 3 is in the emissions caused by transportation as a consequense of Finnish-made balcony glazing longer transportation distance. In Canada, transport accounts for 9 % (15.9 kg CO_2-Equiv.) of total emissions, while it accounts only 3 % (4.9 kg CO_2-Equiv.) of total emissions in a corresponding case in Finland, see Table 4.

Table 4 show that the absolute values for carbon dioxide emissions will also vary remarkably in the Canadian case, as for glass, landfill site and energy waste in particular depending on the recycling rate. The amount of all carbon dioxide emissions will increase remarkably as the carbon dioxide emissions caused by recycling and material re-production decrease. The impact of the recycling degree is considerable.

Table 4. Carbon footprint of balcony glazing in Canada with optimal recycling and worst recycling

The cause of emission	The case in Canada with assumed 70-97% recycling degree	The case in Canada with recycling degree diminished to a third
	CO_2-Equiv	CO_2-Equiv
Transport by rail	0,2	0,2
Landfill site and energy waste	27,7	81,9
Transport by road	3,9	4,4
Transport by ship	11,8	13,1
Lumon Oy`s balcony glazing plant	52,6	52,6
Recycling and reproduction of material	62,5	26,7
Pallet	5,5	5,5
Flashing (steel plate)	2,4	8,8
Polystyrene (packing material)	3,3	8,4
Aluminum profile	0,5	11,7
Glass	3,3	46,2
Corrugated board (packing material)	0,3	0,6
Total	174,0	260,2

Based on calculations diminishing the recycling degree of materials will increase the amount of emissions arising from the production of materials (glass in particular). Because of the diminished recycling, the amount of landfill site and energy waste grows, and results in an increase in the emissions caused by them. The results show that the recycling of glass in particular is recommendable because of emissions.

According to calculations, the carbon dioxide emissions for the most typical balcony glazing solutions will range from 170 to 250 kg CO_2 in Finland and from 180 to 260 kg CO_2 in Canada.

3.3 *Compensation periods for the life-cycle carbon footprint*

As previously mentioned, the heating energy savings obtained from balcony glazing in high-rise block varied from 1.9–10.4 kWh/m^2/a (3.4–10.7%) and was on average 4.4 kWh/m^2/a (5.9%) in Finland (Hilliaho 2010). Results makes it possible to estimate, case by case, the compensation period variation range and the average value of carbon dioxide emissions during the life-cycle of balcony glazing systems. The emissions caused by the heating energy generated through the district heating system were used as the emissions of energy production. They amount to an average of 220 kg CO_2/MWh (Motiva 2004). It is supposed that climate condition, energy savings and the emissions of energy production are in the same level both in Finland and Canada.

Annual savings in heating energy consumption was calculated for 64 m^2 apartment in high-rise apartment building. Energy savings and their effect on CO_2 emissions are shown in Table 5 in minimum, maximum and average energy saving cases.

Table 5. Annual heating energy savings in single 64 m^2 apartment and the effect on CO_2 emissions.

Case	Heating energy		Emissions
	kWh/m^2/a	MWh/a	kg CO_2/a
minimum saving	1.9	0.122	26.8
maximum saving	10.4	0.666	146.4
average	4.4	0.282	62.0

In average Finnish high-rise apartment building have 42-54 apartments. In the whole building scale average total heating energy saving is 11.8-15.2 MWh/a, which corresponds 2604-3348 kg of CO_2 emissions per year.

Compensation period of CO_2 emissions caused by balcony glazing with different recycling degrees in Finland and Canada is shown in Table 6. The compensation time for CO_2 emissions of balcony glazing could be very short. Both in Finland and Canada CO_2 emissions is compensated in 1.1-1.2 years with saved heating energy of buildings in the cases where recycling degree is high and total heating consumption of building is also high. The average compensation time is 2.6 years in Finland and 2.8 years in Canada. In the buildings, where heating energy saving effect of the balcony glazing is small, the compensation period of CO_2 emissions is 6.1-9.3 years in Finland and 6.5-9.7 years in Canada. However, the compensation period is relative short in all cases compared to service life of balconies or balcony glazing, which is at least 30 years. During the service life of balcony glazing they will save great deal of heating energy and much more CO_2 emissions than their life-cycle carbon footprint is.

Table 6. Compensation period of CO2 emissions in Finland and Canada with different recycling degrees.

	Recycling degree of 60-97 %			Recycling degree of one third	
	CO_2 emissions from balcony glazing	Saved CO_2 emission from heating energy	Compensation time	CO_2 emissions from balcony glazing	Compensation time
Finland	kg CO2	kg CO2/a	a	kg CO2	a
minimum		26.8	6.1		9.3
maximum	162.9	146.4	1.1	249.1	1.7
average		62.0	2.6		4.0
Canada					
minimum		26.8	6.5		9.7
maximum	174.0	146.4	1.2	260.2	1.8
average		62.0	2.8		4.2

3.4 *Correctness of results / factors of uncertainty*

The biggest individual factor of uncertainty in the calculation is that there is no detailed information available on the recycling process and the factor varies, depending on the manufacturing batch. Recycling certainly plays a very big role in the formation of the carbon footprint as it reduces the emissions caused by raw material procurement and waste. The recycling process is of greater significance with increased recycling amounts. It would be good to get some detailed information for the calculation how much energy the recycled materials actually consume during the transformation process from waste to usable products. At present, the calculation has considered general estimates for the processes concerned.

The variation in installation journeys and transport equipment is high in reality, which affects carbon footprint results.

4 CONCLUSIONS

By the end of the year 2012 approximately 60 000 block of flats were built in Finland. Most of the buildings are pre-cast concrete structured with extended concrete balconies supported on frame walls. Since the middle of 1980`s these balconies are typically equipped with balcony glazing. Under Finnish outdoor climate, the heating energy savings achieved through balcony glazing varied between 1.9 and 10.4 kWh/m^2/a depending on calculation case. The average of all cases was 4.4 kWh/m^2/a. Balcony glazing was the most useful at Helsinki in the buildings constructed in the 1970s, with balconies oriented southward and supply air intake arranged through balcony.

According to calculations, the carbon dioxide emissions for commonly used balcony glazing solutions will range from 162.9 to 249.1 kg CO_2 in Finland and from 174.0 to 260.2 kg CO_2 in Canada depending on the degree of recycling. Most of the CO_2 emissions are caused by the production of recycled materials to new usable materials at an optimal recycling degree. The second biggest factor causing emissions at an optimal recycling degree is the energy consumption of balcony glazing manufactures plant.

Emissions from the production of materials will increase remarkably if the recycling degree is diminished. For that reason recycling of materials plays a significant role in the formation of the carbon footprint. At the diminished recycling degree, emissions caused by landfill site and energy waste are the largest cause of emissions. The recycling degree of glass in particular affects the carbon footprint of the chain because of its large mass compared to other materials.

Life-cycle emissions will be compensated in 1.1–9.3 years in the case in Finland and in 1.2–9.7 years in the case in Canada. The average compensation period for emissions is 2.2 or 4.0 years in Finland and 2.8 or 4.2 years in Canada depending on the recycling degree.

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Assessment of carbon footprint of laminated veneer lumber elements in a six story housing – comparison to a steel and concrete solution

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ABSTRACT: Many actions have been taken to decrease the operational energy use in buildings. However, with higher energy efficiency standards, the focus is increasingly shifting to energy demand for the production of building materials and the related greenhouse gas emissions. When moving towards zero emission buildings, the developments of more sustainable bearing structure are of interest. A six story housing complex was constructed in Gothenburg, Sweden in 2012 with a structure made of laminated veneer lumber floor elements and glue laminated beams and columns. The use of laminated veneer lumber has the advantage of being a light weight solution.

Building with wood in Norway is generally regarded as a carbon efficient solution, but the impact of additional materials such as glue and insulation can influence the overall results is of interest. Life cycle assessment is used as a tool to calculate the carbon footprint in the production of the main building materials of the structure. The goal of the assessment is to compare the wood structure as built with an equivalent steel and concrete structure and to optimise the use of materials. The scope of the assessment includes the foundation and elevator shaft, structural beams and columns and the floor elements. The results indicate that the steel and concrete alternative have about 35% higher greenhouse gas (GHG) emissions than the as built wood solution, but that almost half of the total emissions are related to the foundation and elevator shaft.

1 INTRODUCTION

The Norwegian research project KlimaTre aims to increase knowledge on the life cycle environmental impacts of different value chains of Norwegian timber. The project is divided into three sub projects focusing on different parts of the value chain, KlimaVerdi, KlimaModell and FramTre. The goal of FramTre is to increase knowledge on the life cycle environmental impacts of timber construction and this study is performed as a part of the activities in FramTre. Moelven Limtre are involved in the research project KlimaTre and have provided the case study of the six story residential building in Gothenburg, Sweden called Trä8. In the Research project MIKADO, Sintef Building and infrastructure prepared environmental declarations (EPDs) for 10 solid wood products, including the glued laminated timber EPD that is used in this assessment (Wærp et al. 2009).

Traditionally energy use in the operating phase has been the largest contributing factor of the entire life cycle energy use, but as shown in Figure 1-1, adapted from the EEBguide (Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative), the importance of the materials is increasing when moving towards more energy efficient buildings. The material impact is especially important in the short time perspective with the climate mitigation goals by 2020 goal, since the material impacts will occur in the nearest future. By looking explicitly at emissions connected to the bearing systems and possible alternatives one gains better knowledge on how these emissions can be reduced. Gustavsson et al., (2006) concluded that the life cycle GHG emissions from a timber framed building are low compared to a concrete framed building. The study concluded that the climate benefits are largest when the biomass residues from the production of the wood building materials where fully used in the energy supply system. Petersen & Solberg (2002) concluded in their most likely scenario that there can be substantial emission reduction from using glue laminated beams instead of steel at Gardermoen airport.

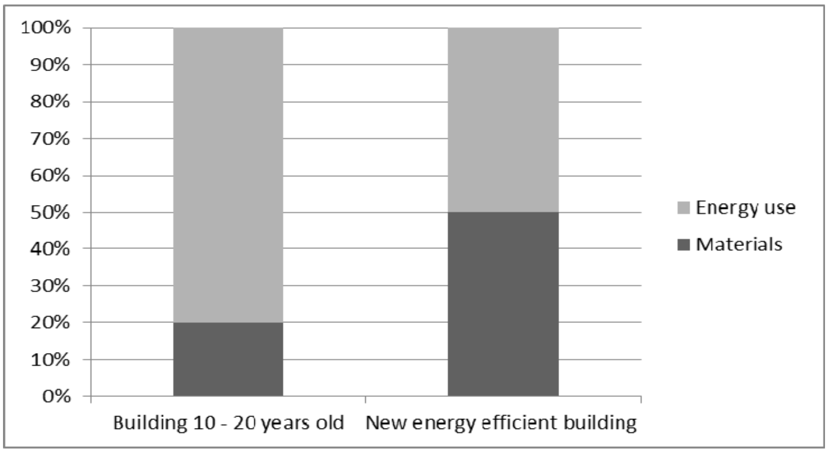

Figure 1-1 The changes of the life cycle material impacts when moving towards more energy efficient buildings. Figure adapted from the EEbguide.eu, 2013

The increased focus of climate change mitigation through low carbon footprint of building materials often leads to methodological questions and disputes. A recent attempt to reduce this dispute is the development of European standards for CEN/TC 350, where EN 15804 and EN15978 are of special interest. This report takes the building Askim Torg hus A (Trä8) as a test case for this standards. This analysis does not analyze the full life cycle emissions, but only the production stage of the different types of building materials.

2 THE BUILDING TRÄ8

The building is located near Gothenburg in Sweden and was built by Moelven Toreboda. General information of the building is given in Table 1. And the building is shown in Figure 2-1.

Figure 2-1 Trä8 in Gothenburg Sweden, (Photo Per Skogstad)

An existing building of two floors was torn down and the new building was built on top of old decking above basement. The wood frame system was chosen because of its low weight. The frame system called Trä8 consists of columns and beams in gluelaminated timber (gluelam) and can have a span up to 8 times 8 meter. The span in this project is up to 7 m. Timber work elements consists of laminated veneer lumber (LVL). These are delivered pre-manufactured. The elevator shaft and the stairway shafts are made in reinforced concrete. In one façade the beam and column system is made of steel and there are diagonal struts of steel in the framework in three corners. The bearing system is shown in Figure 2-2.

Figure 2-2 Gluelam beams and posts in the building (Photo: Per Skogstad)

Table 1. Facts about the building Askims Torg with Trä8

Building owner	Hökerum bygg AB
Area	5000 m^2 BTA, two blocks with common parking and 60 flats
Architecture	Aritekthuset I Jönköping AB
Entrepreneur	Moelven Töreboda
Contract	Property developer, Hökerum bygg AB
Structure	Parking basement in concrete, beams and columns in gluelam, LVL elements for floors. Elevator shaft in concrete with steel for support.

3 METHODOLOGY

3.1 *Goal and scope*

The goal of this assessment is to find the carbon footprint of the bearing system in a six story building built with glue laminated wood frame and to compare it to an equivalent steel and concrete solution. The goal is further to analyze the largest impacts and identify possible means of reduction of green house gas emissions.

The assessment has been conducted on three levels, which are building level, element level and product level. The building level shows the total impact of the equivalent structures and the overall difference of the building alternatives. At the element level, the timber work elements of laminated veneer lumber are compared with pre-casted concrete elements of hollow core slab type where they both have additional materials required for the same functional equivalent. On both the building level and element level, the as built version have been assessed both with generic and specific data, while for the concrete and steel have only generic. At the product level, the different sources of data on laminated veneer lumber (LVL) and gluelam have been assessed for contribution analysis along with the generic data for concrete. SimaPro version 7.3.3 (SimaPro 2012) is used for calculating the emissions and the carbon footprint is calculated with IPCC Global warming potential, measured in kg CO_2-eq. with a 100-year scenario (IPCC 2007).

3.2 *Boundaries*

The analysis is based upon the standards EN15804:2012 and EN 15978:2012 for environmental assessment of buildings. This assessment only includes the products stage, which consists of raw material supply (A1), transport of raw materials to manufacturing (A2) and manufacturing (A3). See Figure 3-1 for the life cycle phases of a building from EN15978. The balconies are not included in the analysis.

A1-3 PRODUCT STAGE			A4-5 CONSTRUCTION		B1-7 USE STAGE					C1-4 END OF LIFE			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4
Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	De -construction demolition	Transport	Waste processing	Disposal

Figure 3-1 This case study includes phases A1-3, the product phase based on the standard EN-ISO-15958.

3.3 *Life cycle inventory*

The material used in the as built construction has been calculated based on detailed construction drawings from the entrepreneur. The parts of the building included in both alternatives foundation are the elevator shaft, structural beams and posts and floors. The inventory, both quantities and environmental data use for the building as built is give in the Tables 2-5 below and the concrete and steel alternative in Tables 6-7.

Table 2. Material use for foundation and elevator shaft

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Concrete	928	m^3	Ecoinvent	-
Reinforcement steel	92 834	kg	Ecoinvent	-

Table 3. Beams and columns inventory for the building as built

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Glue laminated timber	128	m^3	Ecoinvent	Wærp 2009
Supporting steel	10288	kg	Ecoinvent	-
Steel fittings for wood	5055	kg	Ecoinvent	-

Table 4. Flooring elements of laminated veneer lumber type RA100 of 14 m^2.

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Laminated veneer lumber	668	kg	USLCI	Zimmer & Kairi 2001
Glass wool insulation board	75	kg	Ecoinvent	-
Glue	0,919	kg	Ecoinvent	-

Table 5. Additional materials to the looring elements of laminated veneer lumber per m^2.

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Fermacell board	28	kg	Ecoinvent	-
Stone wool insulation board, 25mm	4	kg	Ecoinvent	-
Acoustic profile	1.26	kg	Ecoinvent	-
Gypsum board, standard	9	kg	Ecoinvent	-
Gypsum board, fire	12.7	kg	Ecoinvent	-

An alternative building has been modeled to represent the typical practice for this kind of building. This is a bearing system of steel beams and posts with concrete hollow elements. The concrete hollow elements do not need the additional boards above and under, but have to be 320 mm thick to fulfill the acoustic requirements of Swedish class C. The length of the elements is in this alternative design made with the same as the wood structure. In addition to concrete and steel, 40 mm of screed material and vapor barrier is needed for the concrete floor.

Table 6. Steel beams and columns of building

Input	Use in building		LCI background
	Amount	Unit	Source
Steel	115573	kg	Ecoinvent -

Table 7. Flooring elements of hollow concrete per m^2.

Input	Use in building		LCI background
	Amount	Unit	Source
Vapour barrier, 0.2 mm	0.185	kg	Ecoinvent -
Screed material, 40 mm	72	kg	Ecoinvent -
Concrete hollow element HD320	413	kg	Ecoinvent -

3.3.1 *Use of generic and specific background LCI data*

Specific data on the glue laminated beams is based on an environmental product declaration on glue laminated beams from Moelven Limtre conducted by SINTEF Building and Infrastructure (Wærp 2009). The generic data is all gathered from processes in Ecoinvent version 2.2 (Ecoinvent 2012) except the life cycle inventory of the LVL that was missing in Ecoinvent and therefore taken from the American database USLCI (2012). Specific data is also used for the LVL named Kerto by Finnish manufacturer (Zimmer & Kairi 2002).

4 RESULTS

4.1 *Building level*

The results at building level shown in Figure 4-1 indicate that the carbon footprint of the building as built with generic or specific data have almost the same results. The concrete and steel alternative has an impact that is about 35% higher than the as built wooden building. The building part that has the largest contribution is foundation in all the scenarios and it is also foundation has the same impact on all the scenarios.

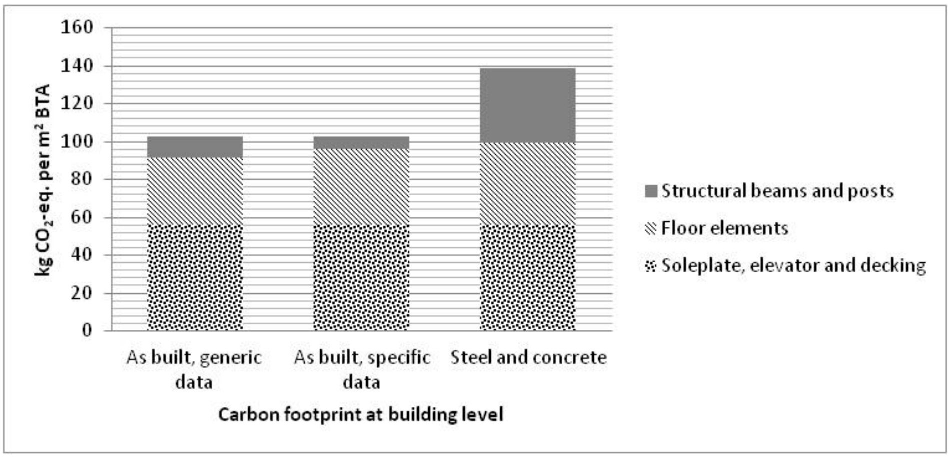

Figure 4-1: Carbon footprint at building level

4.2 *Element level*

Results shown in Figure 4-2 of comparing the flooring elements shows that the as built generic have the lowest impact and the as built with specific data have about 12% higher which is due to higher contribution of the LVL. For the LVL-element, the material needed additional to the element in order to fulfill the functional equivalent to the concrete have about the same contribution as the element itself. The concrete flooring elements have about 25% higher impacts than the generic as built scenario and it is the concrete that contributes most.

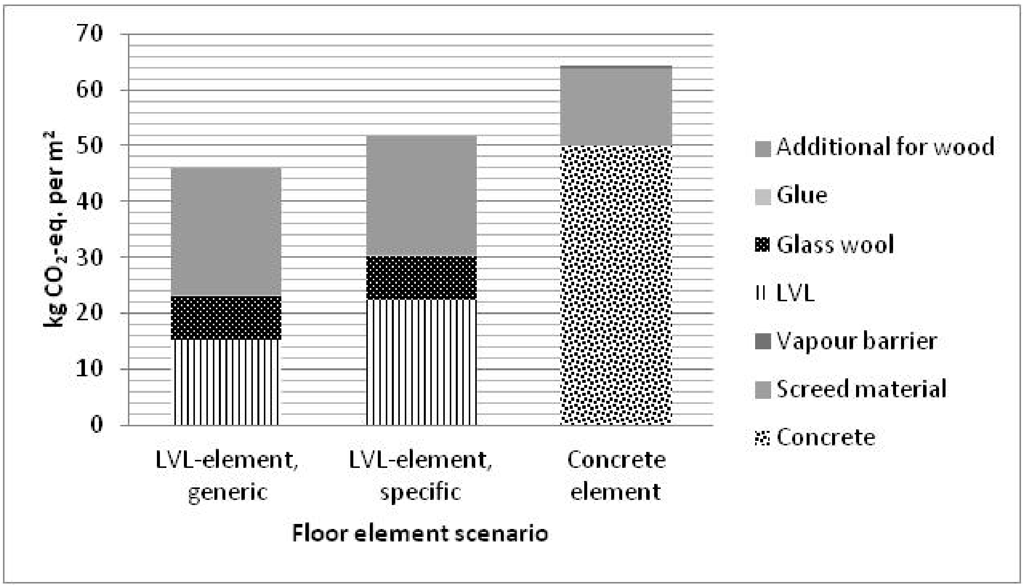

Figure 4-2: Comparing of floor elements at element level

4.3 *Product level - LVL, gluelam and concrete*

The comparing of the LVL material and gluelam for both generic and specific data show large variation in total and in contribution of inputs. Both the generic show large contribution from wood inputs compared to the specific data. The contribution from glue shows large variation between all and especially between generic and specific inventory for LVL.

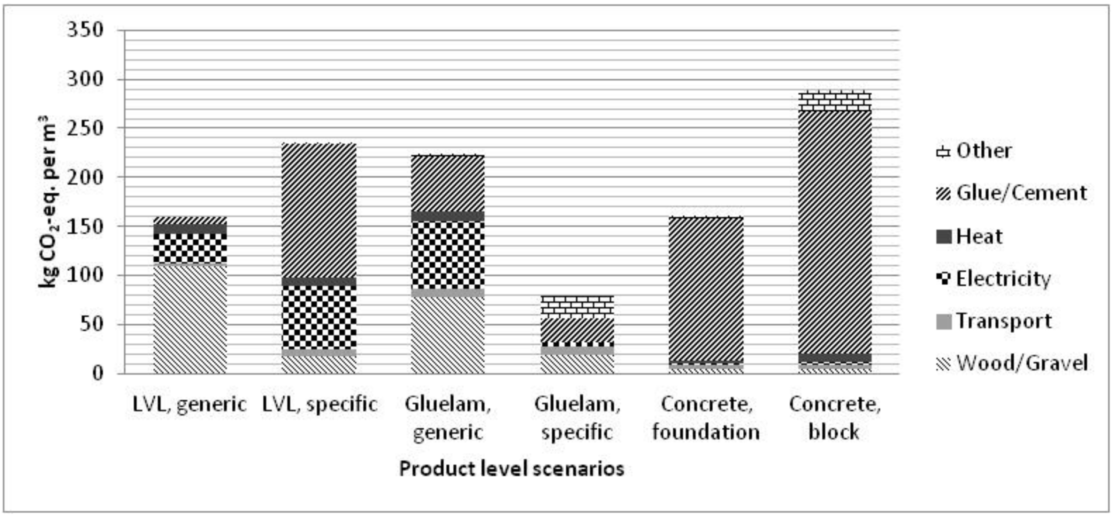

Figure 4-3: Comparing of wood and concrete materials at product level

The Norwegian produced gluelam differs itself from the other wood products by having a much lower total impact and especially the contribution of electricity is low.

The concrete used in foundation is made of cement with blast furnace slag and has only 46% clinker, where the blast furnace slag is considered as a waste input. The cement in concrete on the other hand has 90% clinker at therefore considerable higher impacts (Ecoinvent 2010).

5 DISCUSSION

The carbon footprint of the six-story building as built did not differ substantially between generic and specific data at building level. The difference was, however, quite large when the different materials were compared at product level and it seems that they cancelled out when aggregated to building level. The comparison at element level shows the importance of using functional equivalent where the materials that are needed in addition to wood in the floors are having a considerable impact.

The results showed that the foundation contributed significantly to the emissions of the building. One important reason behind using the Trä8 building system at this place was the low weight making it possible to use an existing foundation from a previous two-story building. Hence, the alternative building of steel and concrete would in reality require more foundation and thus have a higher carbon footprint. Another limitation of the material use in the assumed alternative steel and concrete scenario was that the length of the concrete hollow elements was the same as in the wood scenario. The concrete hollow elements have the strength to cover a length of more than double of this and this could lead to lower steel use.

This study has been limited to the production phase of the materials, but also of importance are the end of life scenarios of the building and especially benefits of recycling and energy recovery beyond the life cycle that are left out. The benefits of wood beyond end-of-life are heat recovery from incineration that is used either for industrial processing or district heating. One other aspect that could have large impacts of the carbon footprint of wood-based materials is the biogenic carbon flows. The wood-based materials are during growth in forest sequestrating carbon dioxide from the air and this is stored in the product until decay or incineration during end of life. As suggested in prEN16485, the biogenic carbon flows will be included in the calculations for GWP for wood products that are sustainably sourced.

6 CONCLUSIONS

The building as built with the Trä8 system shows that the foundation is an important part of the emissions from the structure and an advantage of the light building frame of wood. When assuming the same foundation, the concrete and steel alternative building had 35% higher emissions of greenhouse gasses in production. The comparison at flooring elements between the as built version and a alternative concrete hollow elements, shows the importance of comparing at functional equivalent in terms of requirements to strength, fire and acoustics. At product level the impacts of difference materials varies and especially with generic and specific data, but also the contribution to inputs such as glue.

Further work on the methodology for carbon footprint of wood buildings should be to include end-of-life aspects and the impacts of biogenic carbon flows. At the construction, optimization of materials that are needed in additional to wood in the floor elements and comparing the use of laminated veneer with laminated solid wood in flooring elements.

The practical implication of the results of carbon footprint of the Trä8 system should be to advocate the savings in both carbon emission and potential costs where foundation can be reused because of the lightweight structure. This should be a growing potential with the increasing demand for urban dwellings and the need for higher buildings.

7 ACKNOWLEDGEMENTS

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Designing model house based on the Cradle-to-Cradle methodology

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ABSTRACT: Mozambique is currently experiencing strong growth mainly as a result of the exploration of natural resources, particularly natural gas (Direcção Especifica do Ministério da Planificação e Desenvolvimento, 2013). Strong growth has led to an increasingly rapid urbanization phenomenon that coupled with the absence of environmental concerns. As a developing country, Mozambique should embrace a new building process based on the Cradle-to-Cradle model to respond to the needs of the population and at the same time encompass the three dimensions of sustainable development: economic, social and environmental. The model is based on the resource management and evaluation of environmentally harmful gases from materials since its production stage and during its life cycle through a construction closed-loop and a *waste=food* concept (Braungart & Mcdonough, 2009). The materials are considered *nutrients* for the production of new materials without *downcycle*. This article proposes a design process methodology based on the Cradle-to-Cradle model to better respond to the population's needs, ensuring adequate housing for the community.

1 INTRODUCTION

Developing countries, namely Mozambique, are experiencing a strong economic growth due the natural resources exploration and foreign investment. This growth leads to a set of social and demographics actions like the intern migrations from the rural areas to urban centers, creating highly populated suburban areas. These informal settlements, with a fragile subsistence structure and a lack in the infrastructure system, result in a low quality of life and precarious housing that lead to a public health problem.

The rural settlements, where nearly 70% of the Mozambique's population lives (Organização das Nações Unidas, 2011), have a weak primary sector and an underdeveloped transport network that give rise to another kind of problems: houses that, besides being made with local materials, are very precarious; absence of any strategy of urban design; lack of an infrastructure system, namely health care and education; the isolation of some regions created by a weak access network. The implementation of a (re)settlement process is being hampered by the government insufficient funds combined with an unqualified labour force and industry under development.

This construction model applied in Mozambique is capable to solve the housing problems and create environmental, economic and social positive impacts: "Cradle-to-Cradle posits that mankind can have a positive, restorative, beneficial impact on the environment." (Cradle to Cradle Products Innovation Institute, 2013). The model is associated with a standard house concept that presents economic and environmental advantages. The standard house concept allows an optimization in terms of costs, construction time, and resources management but also in a design strategy that suits the Mozambique social dynamic.

2 DESIGN CONCEPT METHODOLOGY BASED ON CRADLE-TO-CRADLE MODEL

The methodology results in a modular house based on the three Cradle-to-Cradle main areas - materials impacts; embodied energy, emissions and materials reuse; social fairness – which the final solution results from a module made with sustainable materials and from an adaptive house design. This process can be adapted to any territorial and socio-economical context through the manipulation of variable parameters – summary inventory – associated with the Cradle-to-Cradle fixed parameters.

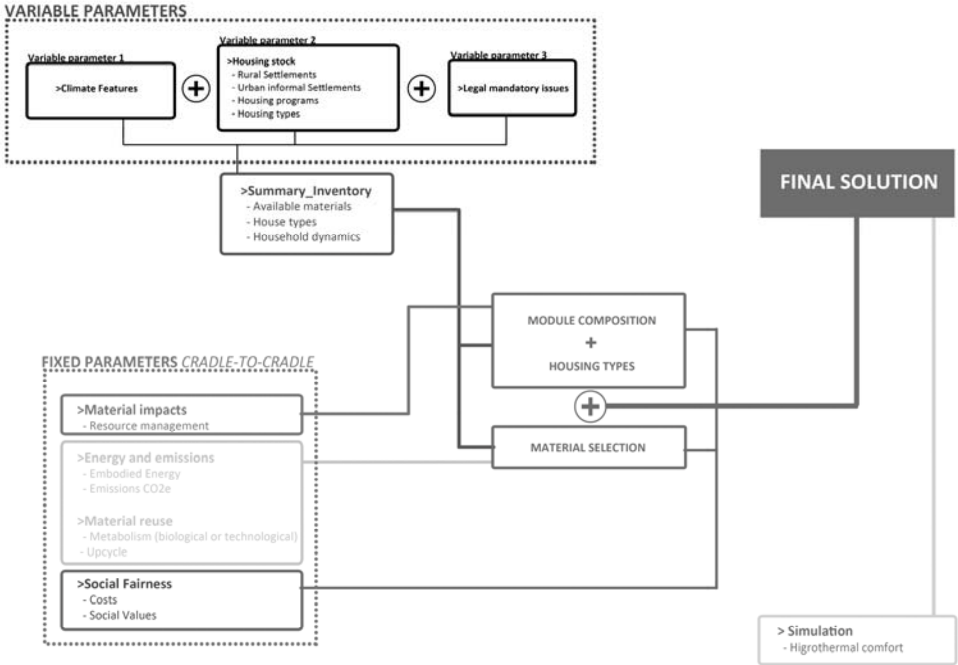

Figure 1. Design concept methodology diagram.

The variable parameters contain the territorial analysis like the climatic features, the housing stock and the legal mandatory issues. These data compilation results in the summary inventory that includes the most common used materials, the house types and the legal issues, which in turn ensure the integration of the house in the social, economic and environmental context. The fixed parameters correspond to an adjustment of Cradle-to-Cradle criteria to the proposed concept methodology, which include material impacts, embodied energy, emissions, materials reuse and social fairness. This methodology allows the creation of a modular house for Mozambique through the combination of the following elements: module composition; housing types; material selection.

The module composition and the housing types make part of spatial concept, whose are resulted by the combination of the summary inventory (territorial data), material impact (resource management) and social fairness (cost and social values). The module composition is based on a raw material management strategy and its associated costs. The module optimization process considers the optimal dimensions and adequate quantities according to the house type and population's needs. The house type followed a resource management strategy combined with the social fairness criteria i.e. room areas that suit the household dynamics and the cultural and social context.

The material selection is the result of the summary inventory with the following Cradle-to-Cradle analysis aspects: embodied energy, emissions, recycling and reuse potential and associated costs.

The final solution is strengthened with a higrothermal simulation, which will reinforce the solution effectiveness as a whole: environment, architecture, construction, economy and thermal comfort. This concept methodology is able to adapt to any territorial context through the combination of Cradle-to-Cradle principles, which corresponds to fixed parameters, with a territorial and social economic analysis that refers to variable parameters.

2.1 *Variable Parameter 1: Mozambique climatic features*

The climatic features analysis is critical for the house effectiveness, covering all the process since the site study to the material selection.

Mozambique's climate is sub-humid and semi-arid, which refers to a tropical and warm weather. This climate is strongly affected by the Indian Ocean monsoon and the southward-flowing Mozambique current (Arnall, 2011).

Table 1. Mozambique climatic features.

Climate area	Average temp. [°C]		Rainfall average/year[mm]	Relative Humidity [%]		Winds [dominants]		Obs.
	M	D		M	D	M	D	
I – North and centre Monsoon climate with 4 to 6 months of dry season	26	26	800					Flood event in Zambezi Basin
II – South Dry climate with 6 to 9 months of dry season	26	20	600	75	65	NE	S	Flood event in Limpopo Basin
III – Mountain Tropical altitude climate	20	20	2000					

* M – monsoon season * D – dry season

The main aspects in Mozambique climate are the warm weather and high relative humidity, which will determine the passive design conception. The passive design and the material selection should focus on ventilation and cooling solutions as well as the material performance under high humidity and radiation, ensuring house quality and thermal comfort.

2.2 *Variable Parameter 2: Mozambique Housing Stock – The Mozambique's House*

The Mozambique housing stock is mainly rural. According to INE Mozambique (National Statistical Institute), nearly 70% of the population lives in rural areas and the projections indicates that in 2040 this rural population will be 60%, remaining a predominantly rural society (Instituto Nacional de Estatística de Moçambique, 2012).

The housing stock is formed by 92,3% of private households, built by the owners with local materials. The shacks are the prevailing house type (69,7%), followed by dwellings (1,6%), flats (0,7%) and precarious dwellings (0,5%). According to table 2, the Mozambique house stock is represented by the use of organic materials such as the cane framework for walls, straw for the roofs and adobe for the floor (Langa, 2010).

The application of organic materials without a preliminary study with a long-term strategy (more durability and quality, less maintenance) is a very precarious solution. Figure 2 shows the most common house types and its constructive systems, which, except the urban house, use organic materials.

Table 2. Buildings materials used in Mozambique and its evolution between 1997-2007.

Element	Material	Current application [%]	1997 [un.hab]	2007 [un.hab]	Variation [%]
Walls	Cane framework	34,6	1 749 322	1 597 832	-8,6
	Adobe bricks	32	687 406	915 878	41
	Canes/sticks	18,3	750 757	848 774	13
	Cement	12,3	276 085	566 996	195
	Masonry bricks	4,9	89 807	227 871	153,7
	Timber	0.9	58 302	42 379	-27,3
Roof	Straw	76	2 984 574	3 468 315	16,2
	Zinc sheets	24	467 497	1 098 353	134,9
	Cement	1,5	62 795	66 329	5,6
Floor	Adobe	23,3	646 240	915 878	41
	Parquet	1,1	47 463	45 149	-99
	Rammed earth	0,9	2 468 084	36 299	98,5

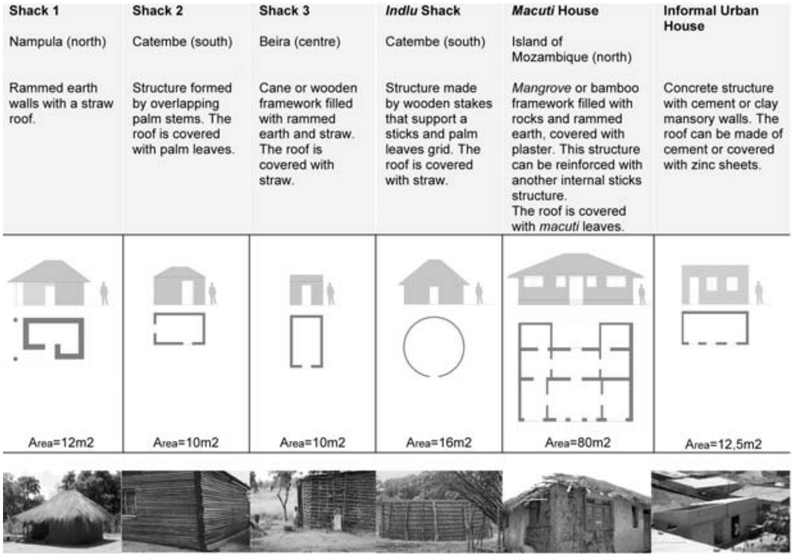

Figure 2. Overview table of housing stock in Mozambique.

2.3 *Variable Parameter 3: Legal Mandatory Issues*

The legislation and regulations that can be useful and applied to the case study are important tools for the concept process because they establish the required minimum standards, namely the room areas and the ceiling height. In this specific case, the legislation applicable refers to the General Regulation of Urban Buildings of Mozambique, RGEU.

Table 3. Overview table of required minimum standards.

Ceiling height	2,80m in multifamily houses 2,60m in single-family houses
Room areas (living room and bedroom)	$\geq 9\ m^2$ Houses with < 5 rooms need one room $\geq 12\ m^2$ Houses with > 5 rooms need two rooms $\geq 12\ m^2$ The room should circumscribed a diameter of 2 m^2
Kitchen	$\geq 6\ m^2$ The kitchen should circumscribed a diameter of 1,6m
Circulation area	$\geq$ 1,20m width

3 MODULE COMPOSITION

The module composition results from the summary inventory with the resource management analysis and social fairness criteria.

The prefabricated module allows a dimension optimization process as well as the quantification of the raw material needed for its fabrication. Modular construction also allows an easier maintenance and space manipulation according to the household needs. The optimization criteria were based on material impacts such as resources management and its costs but also the ease of handling and transport that represents the main costs. The proposal is the creation of a prefabricated modular structure easily carried and assembled, whose filling is made in situ.

The module is composed with an internal structure covered by panels. The composition concept was based in production costs; ease handling without a specialist, resulting in a prefabricated light module that's the filling is made in situ according to the region. This module has four types that allow multiples solutions: wall module; span module; organic module; floor module. The organic module is a variant composed with rammed earth in module outer side, where the user can plant herbaceous plants, creating a green wall. This type of module can improve the interior higrothermal comfort and the air quality, providing a positive impact. The floor module raises the house from the ground, helping the cross-ventilation system and avoiding water entering through capillarity.

For the resources management and its associated costs, it was chosen a wall filled with rammed earth because it is a natural unlimited resource, without any cost, and which the population is familiar with.

The resulted volumes (0,64 m^3 for total volume and 0,42 m^3 for the filling part) show that the module filling material corresponds to 65% of the total volume and the remaining 35% refers to the prefabricated part.

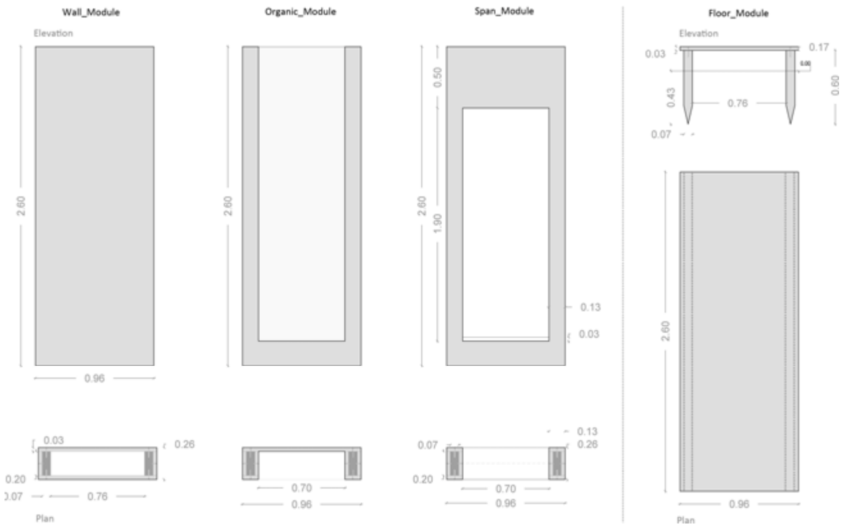

Figure 3. Design concept methodology diagram.

4 HOUSING TYPES

The summary inventory, namely the housing stock study and the legal mandatory issues, associated with Cradle-to-Cradle criteria (material impact and social fairness) lead to an adequate house type.

The housing stock study has shown that the most common house in Mozambique is a single-family rural house, the shack, with only one or two rooms with a courtyard that represents the social and dinner area (including kitchen). The house type pretended to maintain this social and cultural value through the treatment of indoor/outdoor interface. The outdoor, besides the social character, was also considered a food production area i.e. there is an agricultural plot with nearly 42 m^2 for self-production to ensure food self-sufficiency.

For the house type designing were considered the required minimum standards from RGEU in order to ensure quality in a low-cost house concept. These standards are the matrix for module optimal dimension, which in turn will generate the room areas. This prefabricated module allows an “evolutive house” that can keep up the household dynamic (nearly 6,6 children per couple) and its cultural issues (Tvedten, Paulo, & Tuominen, 2009).

The result is an “evolutive house” that starts as a two-bed house because, according to the Mozambique’s statistics, the first child born immediately after marriage. This two-bed house is able to evolve to a four-bed house considering that each room is a double-bed room (capable to support a household with 8 people).

This strategy is economically viable because makes houses cheaper than other solutions but with quality parameters, showing a social concern. It is also environmentally effective because can reduce raw-materials extraction through a resource management and decrease the ground area occupied by buildings, ensuring soil’s permeability.

Table 4. Overview table of Evolutive House areas.

		Area m^2	% Permeable soil
	Lot	181,73	
House type	Two-bed house	66,40	63,47
	Three-bed house	80,27	56
	Four-bed house	92,62	49
Rooms	Living room	20	
	Kitchen	6,80	
	Bathroom	4,50	
	Bedroom	10,30	
	Farm plot	42,73	

5 MATERIAL SELECTION

The summary inventory, particularly the available materials analysis, and Cradle-to-Cradle criteria of embodied energy, emissions and resource management were the basis for the material selection process.

For the calculation of material embodied energy and emissions, the concept methodology uses the Inventory of Carbon and Energy, ICE (Hammond & Jones, 2011). These values relate to a Cradle-to-Gate life cycle in such a way to adapt the calculation process to any territorial context. The majority of the emissions data has been converted to CO_2e, which captures more than just carbon dioxide (methane, PFC’s, etc…). All the final results presented will be shown in m^2, that is to say MJ/m^2 of embodied energy and $CO_2\ e/m^2$ of emissions.

The first step was the identification of the available materials with less environmental impacts based on Cradle-to-Cradle criteria: local and natural materials (biological nutrients) with low $CO_2\ e/m^2$ emissions and embodied energy; materials with reuse or recycling potential without *downcycle*; economically viable materials; materials that are connected with people’s culture.

According to the summary inventory, the most common and environmentally effective materials in Mozambique housing stock are the timber and rammed earth for walls, and the straw as roof covering. The timber with more advantages, is the chosen material for the module (structure and panels), for two main reasons: On the one hand, Mozambique has a developed timber industry with a large potential to develop the national economy, on the other hand, timber is an adequate building material due its technical characteristics like durability and mechanical resistance for example.

Mozambique is one of the major producers and exporters of wood, namely woodlogs and timber, with 67,2% productive forest of the entire national forest area. These productive forests are located in the following regions: Niassa; Zambézia; Tete; Cabo Delgado (Sitoe, Salomão, & Wertz-Kanounnikoff, 2012).

However, the wood industry represents an environmental risk without a reforestation policy and nearly 50%-70% of the wood extraction in Mozambique is informal and illegal, which means not sustainable. This situation brought some species to extinction and the government declared a maximum value for cut of 500 00 m^3/ha per year (Ribeiro & Nhabanga, 2009).

To be sustainable, the timber industry needs to be associated to a reforestation policy to manage the available resources, that is to say the creation of a reforestation cycle 4:1 (a quarter of the reforested area is for cut), allowing a positive ratio. The management of this ratio turns the timber an unlimited resource that creates positive impacts such as the absorption of greenhouse harmful gases, hydric resources preservation and the protection of biodiversity.

The concept methodology has identified the main wood species in Mozambique that are not included in the CITES list (fauna and flora species in risk of extinction) like Pau Preto specie.

Table 5. Overview table of the four main wood species and their usage in Mozambique.

Specie	Description	Usage
Chanfuta (*Azfélia*)	Red tone when exposed; Sapwood pale tone; Medium texture; Medium brightness; Low drying process with very little degradation; Natural durability and good fungus resistance; Very hard word that need appropriate tools to cut; Needs pre-drilling; Weight: 750 kg/m^3.	Used mainly in doors, windows, floors, stairs and outdoor areas.
Missanda (*Erythophleum suaveolens*)	Color: red, brownish or yellow that becomes darker when exposed; Coarse texture and irregular grain; High brightness; 12% humidity; Low drying process with tendency to warping but little degradation; Very hard to saw; Weight: 900 kg/m^3.	Used to floors and heavy construction, namely railroads.
Muninga (*Pterocarpus Angolensis*)	Color: may vary between brown, gold brown, chocolate brown, brick red and brown with red or dark stretch-marks; Sapwood pale tone; Medium or coarse texture; Low drying process but effective by not showing tendency to warping; Easy to saw by equipment or labor; Resistant to fungus, bugs (although is vulnerable to a specified beetle) and sea agents; Weight: 605 kg/m^3.	Buildings and furniture.
Panga Panga (*Milletia laurenti De Wild*)	Color: Brown or dark brown; Sapwood pale tone; Coarse texture; Natural durability and good fungus resistance; Low drying process with minimum tendency to warping but high risk of damaging; Hard to saw, which means that needs equipment to perform; Needs pre-drilling; Weight: 800-870 kg/ m^3.	Buildings.

The table 5 presents the main characteristics such as durability, weight and efficiency to ensure quality (with durability) for an affordable cost (determined by weight and consequently transport). The Chanfuta and Muninga species show more sustainable advantages.

Table 6. Environmental and socioeconomically advantages of Chanfuta and Muning species.

	Advantages	
	Environmental	Socioeconomical
Chanfuta (*Azfélia*)	Native tree of Mozambique *mopane* forest; Despite its low drying process, it has very little degradation; Its durability and fungus resistance increase its long-term efficiency and reduce regular a maintenance; This specie belongs to hardwood trees, which needs special tools and pre-drilling, but it is very resistant and durable ensuring the structure stability.	This specie makes part of the *mopane* forest (the predominant type in Mozambique), which means that exists over all territory, becoming more accessible for the population.
Muninga (*Pterocarpus Angolensis*)	Common specie tin savanna forest in south area; Its light color is able to reflect solar radiation, reducing the heat entrance; This specie does not show tendency to warping which is an advantage in terms of durability and maintenance; Its resistance to fungus and bugs reduces the regular maintenance created by harmful organisms infestation; Its resistance to sea agents ensure a better performance in coastal and marine areas; The saw process can be done by labor which can reduce the energy consume during transformation process; This specie is a lightwood tree, consuming less energy during transport.	Easy saw process that can be done by labor force which means less machines and more jobs; The lightweight of this wood, 605 kg/m^3, reduces transportation cost.

According to table 6, these two species match with the Cradle-to-Cradle model despite the advantages in different fields. On the one hand, Chanfuta specie is a hardwood that needs mechanical processes and consequently increases the energy consumption. However, it is more heavy, more resistant, more durable and with less organic degradation (by bugs, for example), becoming more profitable than Muninga specie. On the other hand, Muninga is lighter and easy to work, which means less transportation costs and less energy consumption. These differences determined the application of each type in the module: the specie Chanfuta is most appropriate for the structure due its resistance and the Muninga specie is more suitable for the panels due its lightness, ease of handling, color and weather resistance.

The timber industry, however, reveals a waste problem that needs a management strategy. The cut process, besides the extraction of wood logs, creates waste like roots, sprouts, branches (with diameters between 6 and 30cm) and leaves (Simonhane, 2013). The exploitation of this organic waste is able to provide another source of income to the communities connected to timber industry and increases its economic development. This waste is usually used for biomass but there are others industrial fields such as: production of consumer goods (objects and furniture); production of construction parts (logs, stakes, etc.); composting for organic fertilizers (Simonhane, 2013).

The use of timber presents also advantages in terms of embodied energy and associated emissions. Timber elements (like the structure and the panels) are able to store carbon for an extended period of time (1m^3 of timber can absorb 1 ton of CO_2) (Lehmann, 2012), creating positive impacts.

According to the Cradle-to-Cradle model, the embodied energy and emissions calculation is an important tool for material sustainability and efficiency evaluation about the energy consumption and harmful gases emissions. The values used for this evaluation are from the ICE, which was considered in *Timber* class the *Laminated Veneer Lumber* type for the panels and *Sawn Hardwood* type for the structure.

Table 7. Embodied energy and emissions of the chosen module materials from the ICE (Hammond & Jones, 2011).

	Embodied energy MJ/Kg	Emissions CO_2 e/Kg	Obs.
Sawn Hardwood	10,4	$0{,}24_{fos}+0{,}63_{bio}$	6,3MJ of embodied energy is from biomass i.e. the fossil energy consumption is about 4,1MJ/Kg.
Laminated Veneer Lumber	9,5	$0{,}33_{fos}+0{,}32_{bio}$	3,3MJ of embodied energy is from biomass i.e. the fossil energy consumption is about 6MJ/Kg.

Table 8. Embodied energy and emissions results for the module.

	Specie	Density Kg/m^3	Mass Kg/m^2	Embodied energy MJ/m^2	Emissions CO_2 e/ m^2
Structure *Sawn Hard-wood*	Chanfuta *(Azfélia)*	750	52,5	546	12,6
Panel *Laminated Veneer Lumber*	*Muninga (Pterocarpus Angolensis*	605	18,5	175,75	6,1

The ICE considers that biomass is carbon neutral and for emissions calculations it was used only the fossil values (*fos*).
None of these calculations considers the absorption of CO_2 by timber.

The tables above (7 and 8) present the results of embodied energy and CO_2e emissions for 1m^2 of each element. The majority of embodied energy values are from biomass (renewable energy source), which reveals that the embodied energy is actually lower. The emissions results show low values, apart from the capacity to absorb CO_2.

The internal connections between the structure and the panel are stainless steel screws and the connectors between modules are made with stainless steel threaded rods. The tables 9 and 10 show the connector's characteristics and its embodied energy and emissions values, and the advantages of applying stainless steel. The stainless steel has high values of embodied energy and emissions due its process with high temperatures. Although, these values are for 1m^2 of material i.e. the elements are screws and rods, which represent a small amount of material and the impacts are less severe.

Table 9. Stainless steel embodied energy and emissions according to ICE.

	Material	Embodied Energy MJ/Kg	Emissions CO_2 /Kg
Screws	Stainless steel	11	6,15
Threaded rods	Stainless steel		

Table 10. Embodied energy and emissions results for the stainless steel connectors.

	Material	(⃠x length) mm	Density Kg/m^3	Mass Kg/m^2	Embodied Energy MJ/m^2	Emissions CO_2 / m^2
Screws	Steel, Stainless, predom. Recycled	20 x 100	8000	160	1760	984
Threaded rods	Steel, Stainless, predom. Recycled	16,5 x 220	8000	132	1452	811,8

CO_2 emissions only.

The Cradle-to-Cradle model refers to a close-loop production cycle, which covers all the material life cycle. The concept methodology considers a reuse process for the module according to its conservation status. The connections are all mechanical which means that allow an easy disassemble in the two Cradle-to-Cradle *nutrients* metabolisms: the biological and the technical. The timber parts make part of the biological metabolism and can be reuse or use as biomass, according to its conservation status. The stainless steel connections can be reused for another modules due its resistance and durability, however, in case of anomalies, can be totally recycled.

6 CONCLUSIONS

This methodology, based on the Cradle-to-Cradle model, is able to be adapting through the manipulation of variable parameters. The methodology aims at setting up a prefabricated modular house solution to the housing problems in a social, economic and environmental context.

The presented prefabricated modular house developed to Mozambique is adapted to an urban densification with informal low-quality houses. The specific solution to study territory as support in the variable parameters identified as: housing stock characteristics; legal mandatory issues and main weather conditions in order to create an adequate solution for territory.

The methodology resulted on a prefabricated module whose filling is made in situ. The dimensions have been optimized according to the legal mandatory issues and to the Mozambique's household dynamics. The present house typology of a two-bed house can evolve to four-bed house, around a central courtyard with a farming area and 50% of permeable surface.

The material selection was based on the available resources and used materials in Mozambique with an embodied energy and CO_2 e/ m^2 emissions analysis that determined its efficiency degree. The module is formed with two *Chanfuta* timber structural pillars covered with *Muninga* timber panels. All the connectors, composed by screws and threaded rods, are in stainless steel, ensuring the durability and quality of the module.

The reuse and recycle criteria was also considered in the material selection process. All the materials were chosen to allow a recycle and reuse process without verify a downcycle or, if the timber has anomalies, provide energy through biomass.

This process is currently under development and the final part corresponds to a higrothermal simulation to evaluate the performance of the whole building in a specified territory, allowing consisted final solutions based on the concept methodology.

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LCA "from cradle-to-cradle" of energy-related building assemblies: Promoting eco-efficient materials

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ABSTRACT: This paper presents a methodology for the Life Cycle Assessment (LCA) of energy-related building assemblies that promotes solutions that use eco-efficient materials. This methodology allows the environmental, energy and economic (3E) LCA from cradle to cradle (3E-C2C) in accordance with European standards. 3E-C2C includes 3E *cost*-C2C, which enables the quantification of all aspects of performance in the same unit.
3E-C2C was applied to 60 external wall alternatives, considering its location in a building in Portugal and using mainly site-specific data for the 16 materials considered. It was found that 3E-C2C allows the characterisation of the benefits and loads of these materials in a clear and quantitative manner. These impacts are expressed in each dimension of performance and life-cycle stage (e.g. production, transportation to site, installation, use stage, and end-of-life), allowing eco-efficient materials to be identified and promoted due to their higher performance.

1. INTRODUCTION

This paper presents a methodology for the Life Cycle Assessment (LCA) of energy-related building assemblies, which was applied to 60 alternatives for external walls of buildings. The results show that this methodology rewards the use of eco-efficient materials by characterising their benefits and loads in each dimension of performance and life-cycle stage.

2. METHOD - 3E-C2C ASSESSMENT

The approach applied allows an assessment of the environmental, energy and economic (3E) life cycle performance from cradle to cradle (3E-C2C) in accordance with European standards (Silvestre 2012). 3E-C2C allows the appraisal, comparison and selection of energy-related building assemblies and was applied to 60 current solutions for external walls of buildings.

2.1. *Scope - system boundaries*

The 3E-C2C approach is defined from cradle-to-cradle, including the life cycle stages of construction products already standardised (see Table 1 - including the extraction and processing of raw materials and the production, the transport, distribution and assembly, use, maintenance and final disposal (CEN 2011b, CEN 2012b). The 3E-C2C approach therefore includes the life cycle stages and/or processes affected by the external walls (i.e. material production and transport, heating and cooling, and maintenance operations), but does not include the 3E impacts of activities during the use stage that are not affected by the exterior wall solution.

2.2. *Scope - declared unit*

The declared unit was defined as 'a square meter of external wall for 50 years', taking into account the use and end of life stages and the reference service life of each alternative. A declared unit, instead of a functional equivalent (CEN 2012b), allows the designer to compare two or more assemblies with selection of the best one, even if they are not functionally equivalent (e.g. external walls with different heat transfer coefficients).

2.3. *Scope - case study*

The model building called Hexa has five residential floors and represents the most common constructive and architectural practices in Portugal. The subject of the study is the flat on the right from an intermediate floor with no building next to the east façade (Figure 1). The location chosen for Hexa was Lisbon, because it is the national metropolitan area with the highest building density. The external walls studied are on the north and south façades (the east façade is considered to be the same for all alternatives). The reference study period was set at 50 years (Silvestre 2012).

Table 1 - Impacts and life-cycle stages in each module of the 3E-C2C approach

3E-C2C module - assembly performance	Life cycle stages					
				Use stage		End-of-life stage - transport, processing and disposal (C2-C4), and reuse, recovery and/or recycling potential (D)
	Product stage (A1-A3)	Transportation to the building site (A4)	Installation in the building (A5)	Energy use for heating and cooling (B6)	Maintenance, repair and replacement (B2-B4)	
Environmental	LCA					
Economic	Market acquisition cost			-	Costs (in the study period for B2-B4, and in year 50 for C2-C4 and D)	
Energy	-			Costs in the study period	-	

Figure 1 - Hexa design drawing of a middle floor: the subject of the study is the flat on the right, with no building next to the east façade

2.4. *Environmental performance of each wall*

The environmental performance quantification of the 3E-C2C method follows the LCA standard method (ISO 2006c, ISO 2006d) and most principles included in standards EN 15643-2:2011 (CEN 2011a) and FprEN 15978:2011 (CEN 2011b), and includes eight impact categories (using CML 2001 baseline - version 2.05) and the life cycles stages described in Table 1.

2.4.1. *Product stage (A1-A3)*

The LCA of the production of the majority of the construction materials (cradle-to-gate approach) resulted from studies completed in national plants (12 out of 16 (Silvestre 2012)) and was performed using SimaPro software. In the remaining analyses the NativeLCA methodology was applied in the selection of LCA data sets to be used as generic in the Portuguese context.

2.4.2. *Construction process stage (A4-A5)*

The construction stage includes (CEN 2012b): the transportation from the production gate to the construction site (A4); the on-site storage of products, the waste of construction products and the processing of product packaging and product waste (A4-A5); and the installation of the product in the building (A5). The 3E-C2C method considers the environmental impacts of all these activities, except any energy or water required for installation or operation of the construction site due to their variable and unpredictable nature.

2.4.3. *Use stage - maintenance, repair and replacement (B2-B4)*

This stage concerns the quantification of the environmental impacts of the materials used in maintenance, repair and replacement operations over the life cycle of the assembly (in the year that they occur) and the frequency of the maintenance work considered in the environmental and economic module is identical. The default value for the reference study period was the required service life of the building, and the estimated service life of each materials took into account the rules and guidance of ISO 15686-1,-2,-7 and -8 (ISO 2006a, ISO 2000, ISO 2001, ISO 2006b).

2.4.4. *Use stage - energy performance (B6)*

The needs of energy for heating and cooling during a building's operation were calculated according to the national regulations for Energy and indoor air quality certification in buildings (RCCTE 2006), which transposes the EPBD (EC 2002), and are the only operational impacts and cost that are meaningful for the assessment of an external wall alternative.

To estimate the environmental impacts of the consumption of energy for heating and cooling, the energy needs of the flat (in kWh; see a detailed description of this calculation procedure in section 2.6.3) by year of the study period were divided by the area of the external wall under evaluation (40.27 m^2) to yield a value related to the declared unit used. This value (in kWh), times the number of years of the study period, was then inputted in SimaPro and the environmental impacts were calculated considering a process to model the domestic consumption for heating/cooling at the use stage that represents an updated Portuguese electricity mix (data from 2011).

2.4.5. *End of life stage (C) and Benefits and loads beyond the system boundary (D)*

At this stage deconstruction was considered to estimate the environmental and economic impacts of transporting and disposing of Construction and Demolition Wastes (CDW) in suitable sites. The cost and the environmental impacts of transporting and disposing of the CDW generated were based on Portuguese case studies that used waste operators and market prices data.

2.5. *3E* cost-*C2C assessment*

The 3E *cost*-C2C method includes an environmental impact assessment method (EIAM) with a weighting step that converts the results of all LCA impact categories into an economic unit. This enables the cost of the environmental impacts to be added to the economic and energy whole-life cost, resulting in an overall single score. This EIAM - *Eco-costs 2007* - is a prevention based single indicator for environmental burdens, whose economic unit is the euro (TUDelft 2011). *Cev* corresponds to the application of the EIAM *Eco-costs* to the LCA results for each life cycle stage.

2.6. *Economic performance of each assembly*

The whole-life cost (WLC) method (ISO 2008) and most of the principles of EN 15643-4:2012 (CEN 2012a) were followed, in order to apply the net present value (NPV) method for each alternative. NPV corresponds to the WLC converted to its present value (using a discount rate), and is comparable to all solutions in the year 0, corresponding to the design phase (Silvestre 2012). The NPV of the declared unit of each alternative was calculated for the study period using equation (1) (Table 2), assuming constant prices (ISO 2008).

2.6.1. *Product and construction process stages (A1-A5)*

The economic cost in year n per square meter of external wall - Cec_n - includes, before the use stage, the market acquisition cost in year 0, which was mostly provided by companies, but obtained also through market surveys, construction firms and building materials suppliers, and based on reference national documents (Silvestre 2012).

2.6.2. *Use stage - maintenance, repair and replacement cost (B2-B4*

The economic cost in year n per square meter of external wall - Cecn - includes the maintenance, repair and replacement operation costs incurred in that year, which were provided and obtained similarly to market acquisition costs.

2.6.3. *Use stage - energy cost (B6)*

The energy cost in year n per square meter of external wall - Ceg_n - corresponds to the energy use expenditure on heating and cooling, calculated by the method described in the national regulations (RCCTE 2006) and in equation (2) (Table 2).

2.6.4. *End-of-life stage (C and D)*

The economic costs in year 50, i.e. end-of-life costs, include only transportation and disposal costs (gate cost or tipping fee) of the building assemblies and expenses and/or revenues from reuse, recycling, and energy recovery, using the approach described in section 2.4.5.

Table 2 - Equations (1) and (2)

Equation	Unit	List of abbreviations
(1) $NPV = \sum_{n=0}^{50} \frac{C_n}{(1+d)^n}$	(€/m^2)	- C_n: cost in year n (€/m^2); - d: real discount rate (without considering risk) applied (3%).
(2) $Ceg_n = 0.1 \times T \times (\frac{Nic}{\eta_i} + \frac{Nvc}{\eta_v}) \times \frac{Aap}{Aew}$	(€/year*m^2 of external wall)	T: cost of 1 kWh of electricity in Portugal for household consumers, without VAT or standing charges (€/kWh) (0.139 €/kWh considering an installation of more than 2.3 kVA); Nic: nominal annual heating needs per square meter of net floor area of the flat (kWh/m^2*year); η_i: nominal efficiency of the heating equipment (1, considering the reference value (RCCTE 2006)); Nvc: nominal annual cooling needs per square meter of net floor area of the flat (kWh/m^2*year); η_v: nominal efficiency of the cooling equipment (3, considering the reference value (RCCTE 2006)); Aap: net floor area of the flat under assessment (129.96 m^2); Aew: total area of the external wall being assessed (40.27 m^2).

3. RESULTS AND DISCUSSION

3E-C2C was applied to 60 common solutions for external walls of buildings, considering single-leaf walls with internal or external insulation and cavity walls, and including 16 components (six thermal insulation materials, two elements of the wall structure, five external claddings and three types of internal coatings). A summarised characterisation of the outer wall alternatives is shown in Table 4.

3.1. *Environmental performance and NPV of the environmental cost (Cev) C2C of the 60 alternatives*

Table 3 shows the extreme results: C2C (stages A1-A5; B2-B4; C2-C4 and D) in environmental category GWP (Global Warming potential, chosen from the eight impact categories considered in the 3E-C2C method); of the potential environmental cost (*Cev*, referenced as "environmental cost" hereafter). Figure 2 presents the potential environmental cost (*Cev*, by the differences in percentage for W1) of single-leaf walls for stages A1-A3, A4 and B2-B4.

3.2. *Economic performance C2C and energy performance*

The extreme results of the NPV of the economic (*Cec*) and energy (*Ceg*) costs (with no weighting or aggregation) are characterised in Table 5. Figure 3 shows the Environmental cost (*Cev*) C2C (stages A1-A5; B2-B4; B6; C2-C4 and D), Economic cost (*Cec*) C2C (stages A1-A5; B2-B4; C2-C4 and D) and Energy cost (*Ceg*) of cavity walls (by the differences in € for W1).

3.2.1. *Discussion of results*

Table 3 shows that the solution with the lowest environmental impacts at product stage (W29 - Figure 2; and W43 on its group of walls) and with the lowest GWP C2C reflects the improved environmental performance of ICB boards in comparison with alternative insulations. The low environmental cost of production and the recycling potential of these boards (namely of on-site ICB wastage) also benefits W3, the solution with the lowest C2C environmental cost. Nevertheless, the high weight of ICB boards sent to landfill, and corresponding transport and disposal, when applied on a VRF system, defines W13 as the solution with the highest end-of-life environmental costs (and W29 on its group of walls). The potential reuse on-site of LWA, and the lower weight of claddings that are transported and disposed of into landfill, places W40 at the other extreme at the same stage (and also in terms of economic cost - Table 5).

Local materials influence the environmental performance of the walls at A4 stage, making W2 the best solution due to the shorter distance of the production plant of stabilized mortar used as render (Table 3 and Figure 2; and also due to the lower weight of EPS boards in comparison with the remaining insulation materials). The production of one-coat mortar and gypsum plasterboard in a farther place makes, on the other hand, W26 the solution with the highest environmental costs at this stage (Table 3 and Figure 2).

Due to the lower waste production on installation (by using only one block and dispensing insulation boards) W23 and W24 present the lowest environmental costs at this stage (Table 3).

Table 3 – Lowest/best and highest/worst (shaded) results per group and overall (*): of the potential environmental cost (*Cev*); and C2C (stages A1-A5; B2-B4; C2-C4 and D) in GWP (in italic)

Group of walls	Life cycle stages (see Table 1)				
	A1-A3	A4	A5	B2-B4	C2-C4, and D
Single leaf walls with external insulation	_W3* C2C_				
	W3	W2* (shorter distance to construction site from the place of production of stabilised mortar used as render; shorter distance to the construction site and lower weight of EPS boards)	W3 (low environmental cost of production and high environmental benefits of disposal - wood recycling - of on-site ICB wastage)	W21* and W22* (GFRC panels)	W6, W7 and W9 (lower environmental impacts of the disposal in landfill - and/or lower weight - of SW, EPS and PUR boards and gypsum plasterboard as internal cladding)
	_W22* C2C_				
	W22* (GFRC panels)	W21 and W22 (high weight of GFRC panels)	W21* and W22* (manufacture and transportation of ancillary materials, i.e. EPS boards, adhesive mortar, metallic accessories and sealants)	(W11 to W20)* (wood-plastic extruded boards in the VRF system)	W13* (weight of the wood-plastic extruded boards with ICB boards sent to landfill, and corresponding transport and disposal)
Single leaf walls with internal, and without (W23-W26), insulation	W29 C2C; _W29* C2C_				
	W29* (ICB board)	W28 and W30 (lower weight and shorter transportation distances of the insulations products)	W23* and W24* (lower quantity of construction wastes)		W24 and W26 (lower weight of the gypsum plasterboard that is sent to landfill)
	_W26 C2C_ (production and transport of claddings from a farther place)				
	W23-W26	W26* (production and transport of claddings - one-coat mortar and gypsum plasterboard - that are produced in a farther place)	W32 (high weight of SW wastage that has to be transported to landfill and disposal impacts)		W29 (high weight of ICB boards that are sent to landfill, and corresponding environmental impacts in transportation and disposal)
Cavity walls	W48 C2C; _W37 C2C_				
	W43 (ICB board in the cavity)	W42 to W45 (shorter distance to construction site from the place of production of internal and external cladding)	W37 and W38 (recycling of stabilised mortar wastage, inexistence of packaging from this product to be processed and reuse on-site of LWA)		W40* (reuse on-site of LWA and lower weight of claddings that are transported and disposed of into landfill)
	_W56_ at A1-A3 (high environmental impacts of the production of SW boards), and C2C				
		W40 (higher weight and/or longer transportation distances of the corresponding claddings and insulation)	W51 (high weight of SW wastage that has to be transported to landfill and to the corresponding disposal impacts)		W41, W42, W44, W45 and W51 (high weight of claddings - and of SW board in W41 and W51 - that are transported and disposed of into landfill)

Table 4 - Outer walls: W1-W22 (Single-leaf walls - External insulation), W23-W26 (Single-leaf walls, no insulation), W27-W36 (Single-leaf walls - Internal insulation), W37-W40 (Cavity walls - Thermal insulation completely filling the cavity); W41-W60 (Cavity walls - Thermal insulation partially filling the cavity)

	External wall																																																											
Mats.	W									W1										W2										W3										W4										W5										W
	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	60
ECS1																							x	x			x	x	x	x	x						x	x			x	x	x	x	x	x	x	x	x	x										
ECS2																									x	x						x	x	x	x	x			x	x											x	x	x	x	x	x	x	x	x	x
ECS3	x	x	x	x	x	x	x	x	x	x																																																		
ECS4											x	x	x	x	x	x	x	x	x	x																																								
ECS5																					x	x																																						
ICS1	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					
ICS2						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
ICS3																											x	x	x	x	x	x	x	x	x	x																								
SW	8					8					8					8											8					8									6					6					6					6				
EPS		8					8					8					8											8					8									6					6					6					6			
ICB			8					8					8					8											8					8									6					6					6					6		
PUR				6					6					6					6											6					6									6					6					6					6	
XPS					8					8					8					8											8					8									6					6					6					6
LWA																																					8	8	8	8																				
CHB 15																					x	x																																						
CHB 22	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																									
CHB 15+11																																					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
LCB 38																							x	x	x	x																																		

Notes:

- External cladding systems (ECS): ECS1 - Adherent (0.02 m render and water-based paint); ECS2 - One-coat mortar; ECS3 - Adherent [0.02 m render, adhesive, (insulation), glass fibre mesh, 0.01 m render and water-based paint] within an ETICS (External Thermal Insulation Composite System); ECS4 - Fastened to a supporting structure - VRF (Ventilated Rainscreen Façades - 0.02 m render in the outer surface of the CHB, and WPC (Wood-plastic composite) structure and boards creating a ventilated cavity); ECS5 - GFRC (Glass Fibre Reinforced Concrete) precast panels with 12 cm EPS boards as void formers;
- Internal cladding systems (ICS): ICS1 - see ECS1; ICS2 - Adherent to the wall structure (adhesive, gypsum plasterboards and water-based paint); ICS3 - Adherent to the insulation material [adhesive, (insulation), gypsum plasterboards and water-based paint];
- Insulation materials (the number is the thickness in cm) - EPS (Expanded Polystyrene), ICB (Insulation Cork Board), LWA (Light Expanded Clay Aggregate), PUR (Polyurethane), SW (Stone wool) and XPS (Extruded Polystyrene);
- Elements of the wall structure (plus stabilised masonry mortar; the number is the thickness in cm) - CHB (Hollow fired-clay bricks, horizontally perforated), LCB (Lightweight - with LWA - concrete blocks, vertically perforated), and CHB 15+11 (cavity wall, plus internal 0.02 m render).

The improved thermal resistance of GFRC panels explains W21 and W22's lower energy cost (Table 5). The lower thermal resistance of LWA makes W37 the worst solution at this stage (Table 5 and Figure 3).

The use of insulating GFRC panels leads to extreme benefits or loads depending on the life cycle stage: their high environmental production cost makes W22 the worst solution at this stage (Table 3 and Figure 2) and C2C; their high weight influence the bad performance of W21 and W22 on the environmental cost of transportation to site (Table 3 and Figure 2); their high need of ancillary materials makes W21 and W22 the worst solutions on the environmental cost of installation (Table 3; and also in terms of economic cost - Table 5); and the high cost of transportation and disposal in landfill of these panels defines W21 as the solution with the highest economic cost at this stage (Table 5). Nevertheless, the lower maintenance needs of these panels provide W21 and W22 with the lowest environmental cost at this stage (Figure 2; and also in terms of economic cost - Table 5). Conversely, the lower durability of wood-plastic extruded boards in the VRF system used in W11 to W20 causes their higher environmental cost at this stage (Figure 2; and also in terms of economic cost - Table 5). The high market acquisition cost of these boards leads to the worst position of W15 at this stage and in terms of economic cost C2C (Table 5). The lower cost of EPS boards places W33 at the other extreme in these two classifications (Table 5).

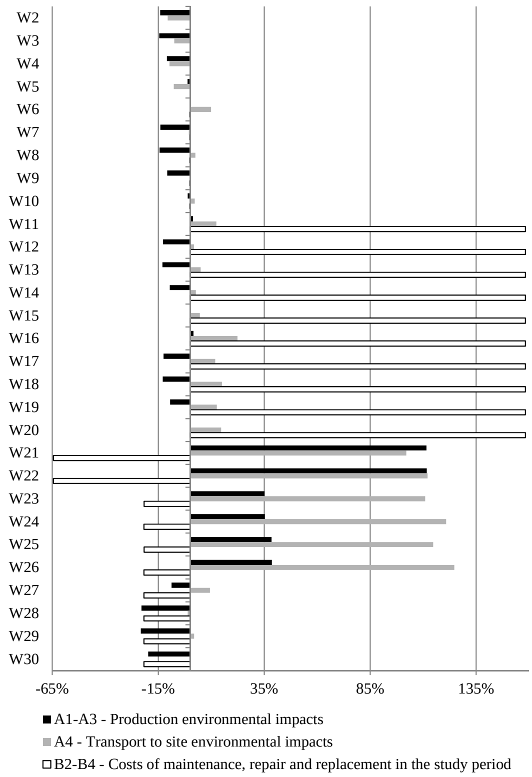

Figure 2 - Potential environmental cost (*Cev*) of single-leaf walls for stages A1-A3, A4 and B2-B4 (differences in percentage for W1)

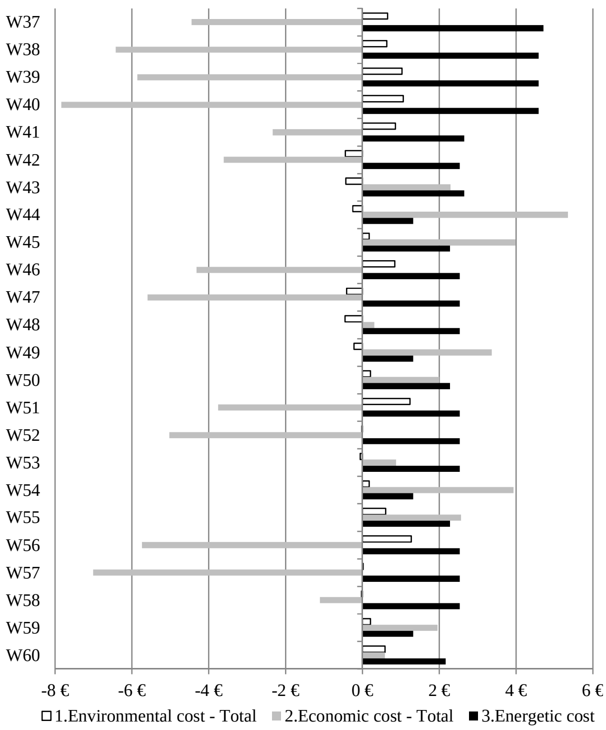

Figure 3 - Environmental cost (*Cev*) C2C (stages A1-A5; B2-B4; B6; C2-C4 and D), Economic cost (*Cec*) C2C (stages A1-A5; B2-B4; C2-C4 and D) and Energy cost (*Ceg*) of cavity walls (differences in € for W1)

Table 5 - Lowest/best and highest/worst (shaded) results per group and overall (*): NPV of the economic (*Cec*) and energy (*Ceg*; at B6 stage) costs

Group of walls	Life cycle stages (see Table 1)		
	B2-B4 (economic costs)	B6 (energy costs)	C2-C4, and D (economic costs)
Single leaf walls with external insulation	W7 at A1-A5 (Market acquisition cost in year 0) and C2C		
	W21* and W22* (GFRC panels)	W21* and W22* (GFRC panels)	W19 (lower volume of insulation material that is transported to landfill)
	W15* at A1-A5 (wood-plastic extruded boards in the corresponding VRF system) and C2C		
	(W11 to W20)* (wood-plastic extruded boards in the VRF system)	W1 to W3, W6 to W8	W21* (cost of transportation and disposal in landfill of its heavy claddings)
Single leaf walls with internal, and without (W23-W26), insulation	W33* at A1-A5 and C2C (lower cost of EPS)		
	W23 to W26	W23 to W26	W35 (lower volume of insulation material that is transported to landfill)
	W31 at A1-A5 and C2C		
	W27 to W36	W27 to W29, W32 to W34	W23 (cost of transport and disposal in landfill of its heavier claddings)
Cavity walls	W57 at A1-A5 and C2C		
	W41-W60	W44, W49, W54 and W59	W40* (reuse on-site of LWA and sending less demolition waste from claddings to landfill)
	W44 at A1-A5 and C2C; W45 C2C		
	W41-W60	W37* (LWA filling the whole cavity)	W41 (SW boards were the only insulation material that was considered to be sent to landfill)

4. CONCLUSION

This paper presents a methodology - 3E-C2C - that rewards the use of eco-efficient materials in energy-related building assemblies by highlighting their environmental benefits and loads in each dimension of performance (3E - environmental, energy and economic) and life-cycle stage.

The result of the application of 3E-C2C to 60 external wall solutions showed that the eco-efficient (3E) performance of materials can derive from their: low production environmental impacts, cost or maintenance needs; high durability or thermal insulation; recyclability; local production. These conclusions were based on the individual analysis of the contribution of six thermal insulation materials, two elements of the wall structure, five external claddings and three internal coatings, mostly using site-specific data. In conclusion, from the extensive sample analysed it was possible to confirm the benefits of using 3E-C2C in the design of energy-related building assemblies to reward solutions with eco-efficient materials.

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Reducing fossil based energy consumption and CO2 emissions in the construction sector

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ABSTRACT: This work aims to study how the environmental impact of the construction industry can be reduced, being this industry the one that requires a higher fossil based energy and natural resources consumption.
The first part deals with the passive systems and Biomimicry, as ways to obtain a natural heating and cooling, with the renewable energy systems incorporation in the constructions and with the sustainable gain of using timber and cork in construction.
Secondly, three case studies that put into practice the covered topics will be presented.
The main conclusions are that a natural heating and cooling allow a great reduction in fossil based energy consumption and correspondent carbon dioxide (CO_2) emissions, being this reduction also achieved by using renewable energy as an alternative energy source and by using timber and cork as construction material, mostly due to their ability to retain CO_2.

1 INTRODUCTION

According to the Fourth Assessment Report, prepared and presented in 2007 by the Intergovernmental Panel for Climate Change (IPCC), the increasing concentration of greenhouse gases (GHG) on the atmosphere, will cause a global warming around 1,8 to 4 degrees celsius until the end of the century.

This document also states that due to this increase in temperature, not only the sea level will rise up to 58 cm, occupying huge portions of land, but also the resulting heat waves and droughts can cause a large and burdensome reduction in food production.

Data from the European Union indicates that the construction sector is the one with higher fossil energy consumption (Europa, 2012), and therefore one of the highest responsible in CO_2 emissions to the atmosphere.

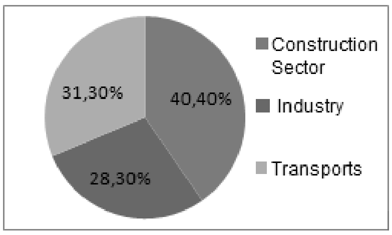

Figure 1 – Energy consumption of the different sector of activity (Europa, 2012)

Studies indicate that in the major European capitals, this sector is responsible for about 25% of the total annual emissions of this gas (Giaconia et al., 2010), and that it also accounts for 20 to 50% of the natural resources consumption (Andreis et al., 2009).

This work studies three crucial points to a greater sustainability in the constructions sector:

- Natural heating and cooling of buildings as a way to reduce energy consumption associated with the artificial ones;
- Use of renewable energy production systems, incorporated in buildings as a clean and pollutant residues free alternative to the fossil energy;
- Use of sustainable materials, wood and cork, with low embodied energy, originated in renewable sources and with high possibilities for reuse or recycling.

The natural heating and cooling of buildings can be performed either by passive systems or by a new philosophy called Biomimicry. Both use the heat transfer principles of the materials, avoiding the high energy consumption that is used by the artificial systems.

The use of renewable energy production systems allows buildings to use a cleaner energy, constituting themselves a sustainable alternative to the fossil based energy.

Finally, the use of wood and cork as construction materials can bring about a huge reduction on the environmental impact that buildings represent. These are not only renewable materials but also they have the unique capability to retain CO_2 from the atmosphere.

2 NATURAL HEATING AND COOLING OF BUILDINGS

Reducing the energy consumption of buildings, in the use phase, is one of the major goals of the construction industry. According to 2010 data, in Portugal, this phase accounts for approximately 30% of the total energy consumption. This value corresponds to an emission of 4,5 million tons of CO_2 to the atmosphere (INE, IP/DGEG, 2011).

This chapter describes two ways of reducing this excessive consumption, both making use of natural heating and cooling. One refers to the passive systems that can be incorporated in buildings, and the other, Biomimicry, is based in a new way of thinking the man made products, seeking inspiration on natural structures.

2.1 *Passive systems*

Passive system can be defined as the process of cooling or heating the interior spaces of a construction without energy consumption.

These systems are based on physical principles, such as thermal radiation, conduction and convection, and take advantage of some material properties such as thermal emissivity, conductivity and inertia.

2.1.1 *Passive heating systems*

The natural heating of the buildings can be performed by the use of passive heating systems in three distinct ways:

- Direct solar gains – this consists of a set of constructive options that allows a heat gain by direct solar exposure. Therefore, the south facade should have a larger total and glazed area, the opaque exterior areas should be well thermally insulated and double glazing should be used;
- Indirect solar gains – The heat is accumulated in the building elements that have a good thermal inertia, and then, it is released into the interior spaces when the temperature drops by thermal radiation or by the creation of convection currents. The trombe walls, the water roof and wall, and the thermal storage floor are examples of the most significant of these systems;
- Isolated solar gains – The heat is produced and stored in special areas, separated from the building, such as greenhouses or thermosyphon systems. This heat, generated in these areas, is transferred to the interior spaces either by conduction and radiation, through the wall separating these two independent spaces, or by thermal convection, in which there

are ventilation holes establishing contact between the heat production areas and the interior building spaces.

2.1.2 *Passive cooling systems*

There are several ways to carry out the natural cooling of buildings. For instance, the east and west facades should have a minimum total and glazed areas, there should be an exterior shading system (especially on those facades), and the color of the exterior facades should be bright.

Also the use of natural ventilation, solar chimneys (preferably with solar chambers), static vacuum, soil cooling systems and night radiation are examples of ways to obtain natural cooling.

2.2 *Biomimicry*

The Biomimicry, in construction, is the study and observation of nature in order to apply its principles in the structures built by man. A low energy consumption can be obtained by the observation of natural structures, successful in its heating and cooling.

As examples of this new line of thinking in the construction, we have the Vawtex ventilation system, the Esplanade cultural complex, and the Eastgateshopping center.

The Vawtex ventilation system is inspired by the fruit samara seeds. Their propellers allow the wind capture in almost any direction, and do not represent any type of fossil energy consumption.

Regarding the Esplanade Theatre, located in Singapore, the geometry and dimensions ratios of the aluminum panels that coats the exterior surface, are inspired by the durian fruit. These panels promote the glazing areas shading and avoid an excessive thermal gain.

The Eastgate shopping center uses a natural cooling system inspired on the termites nests, which is based on a set of solar chimneys that promote the release of the hot air existing inside the structure.

3 RENEWABLE ENERGY PRODUCTION SYSTEMS

Besides all the constructive options and passive systems referred, there are several renewable energy production systems that allow a gain of sustainability in the constructions. These systems permit the consumed energy to be originated from natural and inexhaustible sources such as the sun, the wind, the water and biomass. This energy is clean and free of pollutant residues and does not contribute to the increase concentration of CO_2 in the atmosphere.

3.1 *Solar Energy*

The use of solar energy in buildings, consists on capturing light energy and thermal energy from the sun radiation and convert it into electrical energy for its consumption.

There are two main systems that can produce this type of energy: the photovoltaic panels and solar collectors. The photovoltaic panels produce electric energy through the solar radiation. This technology can generate 150 W through 1 m^2 of panel using the sunlight at noon (Andiv, 2009). The solar collectors are used to warm the water that is consumed in buildings.

3.2 *Wind Energy*

The wind towers have blades that, attached to a generator, can produce electrical energy through its movement, imposed by the wind.

Perhaps the most representative example of the application of a system of wind energy production in a construction, is the Oklahoma Medical Research Foundation headquarters, a project from the Venger Wind and SWG Energy Enterprises.

This building located in Oklahoma, U.S, has a wind energy production system composed by eighteen wind turbines with omnidirectional vertical axis, located on the roof.

Each has a capacity of 4,5 KW, and their shape around a vertical axis allows them to operate even with very low wind velocities. The production capacity of this system is thus maximized, making this a virtually self sufficient building in energy terms (Singh, 2012).

3.3 *Hydraulic Energy*

The hydraulic turbines are designed to transform the kinetic energy and pressure of water flows into mechanical energy. This transformation is accomplished by the use of a torque and rotational speed. The mechanical energy is then converted into electrical energy by coupling to the turbine specific devices for this purpose, such as compressors and electric generators.

A Japanese company, the Ibasei, presented in 2012 a model of a smaller turbine for use in buildings. According to this company, it can create 250 W from a stream of water with a velocity of 2 m/s, and five turbines together can generate about 1 KW (Quick, 2012).

3.4 *Biomass Energy*

When applied to energy production, this term represents the forestry and agriculture waste that can be used to produce thermal energy. This process passes through the burning of these organic wastes, and there are many industries, such as the wood and cork, that use this as a primary energy source, reducing their own industrial residues.

Biomass energy can be considered renewable because its source is in constant growth and the CO_2 emissions can be considered as zero since it only returns to the atmosphere the amount of this gas that it has previously retained.

When incorporated in housing, this renewable energy source can be used in heat recovery systems like the designated heat exchangers. These systems are used for heating the interior spaces and can present, by the use of a closed burning area, a efficiency up to 88% (construçãosustentável, 2012).

4 WOOD AS A SUSTAINABLE STRUCTURAL BUILDING MATERIAL

There are two natural characteristics of wood that distinguish it, in sustainable terms, from all the other building materials. They are its capacity to retain CO_2 from the atmosphere, and the fact that wood is an unlimited resource, when forest management is well done. These two properties reveal a part of the full potential of this material as a sustainable alternative to concrete or steel. This potential is also reflected in a low embodied energy, an excellent thermal insulation capacity that allows a reduction of the energy consumption to artificial heating and cooling, and the possibility of reuse or recycling in new constructions.

4.1 *Contribution to the CO2 Reduction in the Atmosphere*

The trees, in their photosynthetic process, use and absorb CO_2 in the formation of their wood tissues. This capability is maintained by the wood construction products, even after they are processed.

Studies indicate that 1 m3 of timber can hold about 0,9 tons of CO_2 over its lifetime and that this volume of wood needs 1,1 tons of this gas less than concrete to be produced. Adding these two values it can be said that the use of wood in constructions allows a saving in the CO_2 emissions of about 2 tones (Vhn, 2003). It is estimated that an 10% increase in the number of timber houses in Europe would correspond to 25% of the reduction of CO_2 emissions proposed in the Kyoto protocol (Jular, 2010).

4.2 *Renewable Resource*

Besides its ability to absorb CO_2 from the atmosphere, wood has another property that makes it one of the most environmentally friendly building material: it is a renewable resource.

When forest management is well performed, the wood presents itself as an inexhaustible natural resource, unlike concrete and steel whose raw materials come from limited sources.

About 30% of planet Earth is covered with forests (Nabuurs et al., 2003), 5% of which belong to Europe (FAQ, 2002). Data from 2003 indicates that this value of European forests corresponds to an area of 150 million ha. This way, it´s possible to understand the huge natural resource that forests represent (MCPFE, 2003).

This huge area is constantly growing and it is estimated that each year, European forests increase by about 510 000 ha (EFI-Presentation, 2004).

The excellent forest management that exists in Europe allows that only 64% of this annual growth is consumed and used in the timber industry (Parviainem, J., 1999).

4.3 *Embodied Energy*

The embodied energy of a construction material can be described as the energy required for its extraction, production and processing. Compared to other materials such as concrete, steel and aluminum, wood has a lower value of embodied energy. For instance, to produce 1 ton of wood compared to the referred materials we have that (Caridade, 2010):

- It requires 4 times more energy to produce a ton of concrete;
- It takes 60 times more energy to produce a ton of steel;
- It takes 250 times more energy to produce a ton of aluminum.

4.4 *Energy Saving in the Use Phase of the Buildings*

The wood cellular structure possesses excellent properties as a thermal insulator. It is estimated that its ability to insulate a space is about six times more efficient than bricks, fifteen times more than concrete, four times more than steel and one thousand seven hundred and seventy times more than aluminum.

Its lower thermal conductivity allows that a wooden wall 2,5 cm thick can obtain the same thermal insulation than a 11,4 cm thick concrete one (Santos and Matias, 2006).

4.5 *Reuse and Recycling Potential*

Wood, as a construction material, offers an enormous potential for either reuse or recycling. This will always depend on the state of preservation of its elements. If they are in a good state they can be reused after a small restoration and maintenance. If not, they can easily be recycled into other wood based products.

It can also be used as a source of biomass energy, representing a zero CO_2 emission and a renewable energy source for the wood industry which uses this type of energy in the production of its goods.

4.6 *Wood Based Products*

The appearence of wooden based products that make use of an alternating arrangement in the fiber directions, allowed the building in height of timber constructions. The improvement in terms of structural strength enabled the increasingly emergence of this type of constructions in several countries, of which England and Canada are the best example.

Of these products one offers the best resistance conditions maintaining a high flexibility in its utilization on constructions: the cross laminated timber panels. These are composed of laminated layers of wood, placed perpendicular to each other and in an odd number. The number of layers available on the market, usually vary between 3, 5 or 7.

5 CORK AS A SUSTAINABLE THERMAL INSULATION MATERIAL

Cork offers, like wood, two qualities that make it one of the most environmentally friendly and sustainable material that can be used in construction: it´s a renewable material that has the unique capability of retaining CO_2 from the atmosphere.

In terms of CO_2 retention, cork, as well as wood, is the only material used for construction with the capability to do so. Even after being processed, it continues to retain this gas in about half its dry weight. It is estimated that annually 4,8 million tons of CO_2 are retained by the cork oak area in Portugal.

The outstanding properties of cork provide a wide application in the construction industry and can be used for coating vestments, expansion or compression joints, thermal, acoustic and vibration insulations.

Its main features as a construction material are as follows (APCOR, 2011):

- It is root-proof and is therefore a product with long life span;
- It offers an excellent sound, vibration and thermal insulation;
- It does not react with chemical agents;
- It has a good fire behavior and releases no toxic gases when burning;
- It is 100% natural and recyclable;
- It´s a renewable material, strongly implanted in Portugal.

5.1 *Insulation Cork Boards*

As a thermal insulator, this material is used in the form of cork expanded agglomerated boards, also called ICBs. The type of cork used for its production has a high content of natural resin which, through its exudation, enables the natural agglomeration of its granules, all without using any synthetic compound, making this a 100% natural and environmental product.

6 CASE STUDIES

There are three excellent examples that show the sustainability gain when using all the diferent systems of natural heating and cooling, renewable energy production, wood and cork as construction materials. They are:

The Solar Building XXI, which uses many of the refered passive cooling and heating systems as well as a great incorporation of a photovoltaic system for solar energy production;

The Standthaus Murray Groove, the biggest multi-family building with nine floors, structurally built only with cross laminated timber panels;

And the Portuguese pavillion, presented in the Shangai World Expo of 2010, entirely coated externally with cork.

6.1 *Solar Building XXI*

Planned and built by the department of renewable energy from the National Institute of Engineering (INETI), the solar building XXI concept is to demonstrate the sustainability and economic benefits that can be obtained by incorporating solar energy production systems in constructions.

There is a total of 76 panels placed on the south facade, totalizing an area of 96 m², that are responsible for producing 30 kW.h per day. This value corresponds to about 40% of the building total energy consumption *(IEFP, 2012)*.

Also in the parking lot 100 photovoltaic modules were placed, totalizing an area of 95 m², that produce 33% of the total energy needed to “feed” the building *(IEFP, 2012)*.

Adding up these two values, it´s concluded that an amazing value of 73% of the total energy needed is produced entirely by a renewable and non pollutant source: the sun *(IEFP, 2012)*.

6.2 *Stadthaus Murray Grove*

The Stadthaus Murray Grove, built in Hackney, England, is a nine-floor building constructed with wood, more specifically cross laminated timber boards (CLT). This is a demonstration of how nowadays it´s possible to build in height using wood as a structural material.

In environmental terms, this building has enabled savings of carbon emission to the atmosphere of about 124 tons, this during the construction phase. If we add up the 188 tons of CO_2

that the 900 m³ of wood used in the building will retain during its lifetime, we end up with a total saving of 312 tons of carbon (TRADA, 2009).

The use of CLT boards allowed a construction time 30% inferior to the one that would be needed for a reinforced concrete building. This way a construction that would take 72 weeks to be prepared, took only 49 weeks (LIDDEL, 2013).

Also a mechanical ventilation heat recovery system installed in every room allowed the retaining of 70% of heat that would be lost to the outside (LIDDEL, 2013).

6.3 *Portuguese Pavilion at Shanghai World Exhibition 2010*

Under the theme “Better City, Better Quality of Life”, the 2010 world expo exhibition in Shanghai focused on the urgent need for sustainable options, not only in the construction sector and development of large urban centers, but also of our own society and culture.

Designed by the architect Carlos Couto, the Portuguese pavilion used cork as its main constructive material. It was totally coated in insulation cork boards (ICB), making this one of the most environmentally friendly pavilions of all the exposition. 3.640 m² of cork where used in the outer facade totaling over 240 tons of this material. The inner area covered with cork reached 1.100 m² and it was also used 780 m² of a product based on cork and rubber to add soundproofing to the projection room of a promotional video about the sustainable measures that are being taken in Portugal (BCORK, 2011).

7 CONCLUSIONS

In the initial phaseof constructions, the use of the sustainable and renewable materials wood and cork, allows a large environmental gain and a great reduction of the ecological footprint of buildings. These materials have the unique ability to retain CO2 from the atmosphere and have both low embodied energy;

Both timber and cork industries use their own production residues to produce biomass energy. This energy is used to manufacture their products;

In the utilization phaseof the buildings, the natural heating and cooling passive systems allow a great reduction on the fossil energy consumption used in the artificial ones;

In this passive systems it´s crucial to use materials with thermal inertia. Wood as a construction material has not a good behaviour in this field but nevertheless it has an excellent thermal insulation capacity, allowing the interior spaces to be heated more rapidly than in a traditional concrete or brick wall solution;

Renewable energy production systems present themselves as a key factor in reducing the energy consumption of buildings. They allow to obtain a clean and pollutant free residues energy, lowering, this way, the CO2 emissions that buildings represent;

In the end of the life of the buildings the environmental gain of using wood and cork is also evident. The products based on these materials not only have a great reuse or recycling potential but they can also be used as a biomass energy source, producing the necessary energy for both these industries, in the production of their goods, or even in other industries.

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Life Cycle Assessment of an ETICS system composed of a natural insulation material: a case study of a system using an insulation cork board (ICB)

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ABSTRACT: External thermal insulation composed systems (ETICS) are insulation solutions available in the market with indisputable advantages regarding mechanical, thermal and hygrometric performance. These characteristics result in a reduction of energy consumption associated to heating and cooling of buildings with a consequent contribution to sustainability in buildings. Nevertheless, it is also necessary to evaluate these systems under international standards regarding the use of raw materials, production processes, transport to the construction site, use stage and end of life. This evaluation is then translated into potential environmental impacts distributed in different impact categories. This paper shows an overview of the Life Cycle Assessment (LCA) study developed to obtain an Environmental Product Declaration (EPD) according to EN 15804 and ISO 14025 of an ETICS system with an insulation cork board, presented by Saint-Gobain Weber Portugal. In this paper, a critical analysis of results is also provided, suggesting a set of potential improvements for each impact category.

1 INTRODUCTION

1.1 *Life Cycle Assessment (LCA) Type area*

As society becomes more concerned about global warming and other environmental issues, people start to become more aware of their day-to-day choices and are looking to find ways to minimize their negative impact on the environment. These increasing concerns with environmental issues triggered a subsequent demand from companies in ways of assessing the impacts of their activities in the environment. They are now investigating ways of improving the environmental performance of their products by substituting raw materials by recycled ones, reducing energy consumption and adopting strategies on pollution control. The LCA is one of the tools that have been used in the construction industry since the 1990s to evaluate the “cradle-to-grave” impacts of its activities. This approach considers the activities from the extraction of raw materials from the earth, the production process, the transportation to the construction site, installation, use and end-of-life stages. This evaluation is a great way to have a global view of the environmental impacts of the product in its whole life-cycle and to understand the conflicts between selection of products and processes, making it easier for the consumers or decision-makers to choose between the product or process that implies least environmental impacts.

1.2 *Environmental Product Declarations (EPD)*

According to ISO 14025:2006, the EPDs are environmental declarations that show quantified environmental information about the life cycle of a product to allow comparison between products that are used to performing the same function. This standard establishes the principles and specifies the procedures for developing EPDs and other Type III environmental declarations (verified by a third independent party) and programs.

EN 15408:2012 is a later European standard that, in accordance with ISO 14025, was created to provide the structure or core Product Category Rules (PCR) to ensure that all EPDs of construction products, construction services and construction processes are derived, verified and presented in a harmonized way.

2 METHODOLOGY

2.1 *Structure of the study*

The presented study was developed in compliance with the principles in ISO 14025 and EN 15804 standards. The main structure of the LCA study is divided in 4 chapters:

(1) Goal and scope, where it is defined the objectives of the study, the functional unit used, the product's description and application and also the boundaries of the system analyzed.

(2) Inventory Analysis, where it is identified and quantified the energy, water and resources used, the emission of pollutants into the air, water and soil and waste production. In this stage it is also indicated the calculation procedures and requirements considered in collection of data and use of average data.

(3) Impact Assessment, where the inputs and outputs of the system are translated into potential environmental impact, divided in different impact categories.

(4) Interpretation, where the results of the inventory analysis and the impact assessment are analyzed and discussed, considering the uncertainty and assumptions used in the study.

3 GOAL AND SCOPE

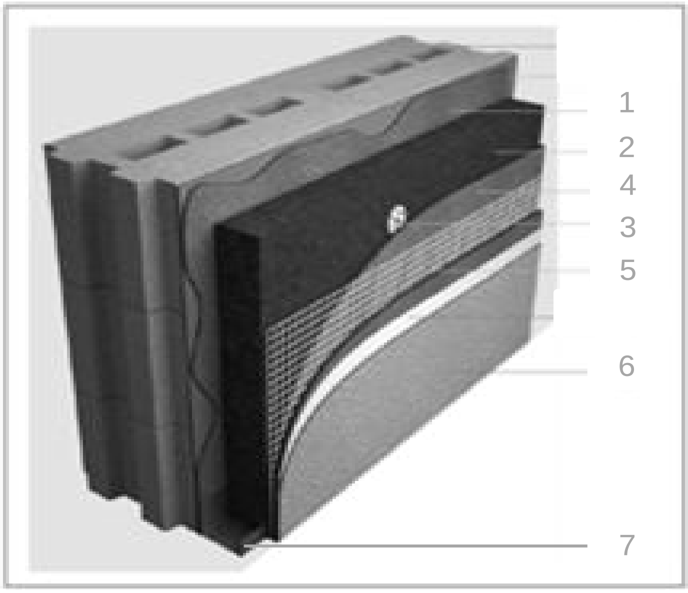
The developed study aims to determine the environmental impacts of the ETICS system with an insulation cork board from Saint-Gobain Weber in order to obtain an EPD on the basis of EN 15804 and ISO 14025. The information on the EPD is intended, mainly, for business-to-business communication. The results of this study will also be used in the improvement of the production process, since the LCA should identify the critical areas and opportunities of improvement. As this EPD will also be available on the website of the program operator, it can consequently be used in business-to-consumer communication.

3.1 *Declared/Functional unit*

Both the inventory and impact assessment stages of this study were developed considering a unit that may be used to compare other composite heat insulation systems. According to the recommendations of the EPD program chosen and other PCR documents, the functional unit adopted to develop this EPD of ETICS system is 1 m^2 of composite heat insulation system with the specified composition and construction parameters of the product.

3.2 *Product description*

The product analyzed is an ETICS system named Weber.therm Natura consisting on different components as indicated on Figure 1 and Table 1.



1 - Mortar adhesive: weber.therm naturcork

2 - Insulation board: weber.therm cork (from Amorim Isolamentos)

3 - Mechanical fixings

4 - Mortar coating (2 layers): weber.therm naturcork

5 - Fiber mesh cloth: weber.therm normal

6 - Finishing: weber.rev natural

7 – Metallic profile weber.them start

Figure 1. Weber.therm Natura system

Table 1. Main components of Weber.therm Natura

Material	Components/function	Quantity per m² of system
Weber.therm Naturcork	Mortar adhesive used for bonding and coating ETICS systems composed by hydraulic lime, white cement, kaolin, mineral fillers, resins, synthetic fibers and special additives. Produced in Saint-Gobain Weber plant in Aveiro.	11 kg
Insulation board of ICB (110 kg/m³)	Insulation Cork board produced by Amorim Isolamentos in Vendas Novas.	4,4 kg
Weber.rev Naturkal	Mineral lime based colored finish for interior and exterior walls. Hydraulic lime, hydraulic binder, fillers, synthetic fibers and specific adjuvants. Produced in Saint-Gobain Weber plant in Carregado.	3 kg
Metallic profile Weber Therm start	Alluminum profile which has the dual function of aiding the assembly of the beginning of the system and provides protection against the penetration of moisture and external aggressions from below.	0,194 kg
Metallic screws with plastic dowels	Steel screws used for fixing the aluminum profile with a plastic dowel	4 units
Plastic fixings	Plastic nails with plastic caps used for fixing the insulation boards	8 units

3.3 *Area of application of the construction product*

The construction product in analysis can be applied for the following purposes:

- External thermal insulation in building façade walls, incorporating insulating boards of natural origin;
- Functional rehabilitation (waterproofing, cracking and aesthetics) and improved thermal insulation of facades in buildings with incorporating insulating boards of natural origin.

3.4 *System limits*

The EPD developed about this ETICS product covers the information module A1-A3 which corresponds to the product stage, comprising the following main stages (in line with EN 15804):

- A1 raw material extraction and processing, processing of secondary material input (e.g. recycling processes)
- A2 transport to the manufacturer
- A3 manufacturing

This product stage includes the provision of all materials, products and energy, as well as waste processing up to the end-of-waste state or disposal of final residues. The system boundary includes also those processes that provide the material and energy inputs into the system and the following manufacturing and transport processes up to the factory gate, as well as the processing of any waste arising from those processes.

Additionally, includes information modules A4-A5 referring to the construction stage, according to EN 15804 which comprises:

- A4 transport to the construction site
- A5 installation in the building

These stages include the transport of the finished product and additional materials to the construction site, energy and ancillary materials required during installation and waste processing up to the end-of-waste state or disposal of final residues during the construction stage.

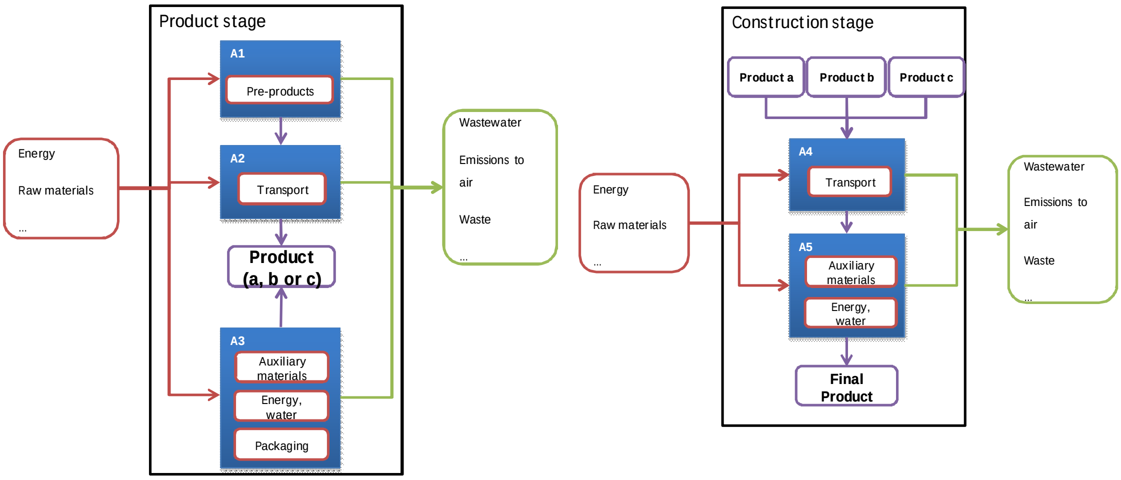


Figure 2. Production and construction stages (module A1-A3, A4 and A5)

Based on presented methodology, it should be considered that were not considered stages as use period and end of life. The main reason is related to the initial purpose of focusing only on the production and application process which are very defendant from the producers behaviors.

4 LIFE CYCLE INVENTORY ANALYSIS

4.1 *A1-A3: Product stage*

4.1.1 *Production of ICB*

ICB is a natural product since the cork granules are aggregated solely by the action of the natural resins contained in cork. The production process begins by grounding raw cork into granules with the appropriate size that are placed in an autoclave. Under the effect of pressure and superheated steam the granules expand and are agglomerated, originating blocks. This process occurs only with the natural resin (suberin) of the raw material, meaning that it does not require any extra use of any adhesives. Once formed, the blocks are forwarded to cooling stage, where recycled water is injected at a temperature of approximately 90 ° C. The stabilization phase, requiring no use of energy, occurs by placing the blocks in the tunnel and then in a natural ventilated space. After the stabilization period, the blocks are ground and cut according to the desired thickness and then packaged.

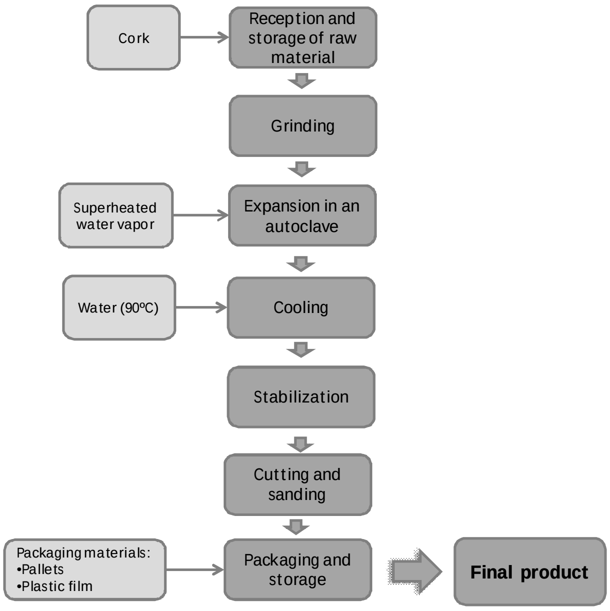


Figure 3. Production process of ICB

4.1.2 *Production of mortar products*

The raw materials are received in tankers, bags or big-bags. Storing bulk materials in silos can be made directly or through pneumatic conveying system.

The final powder product is obtained from the mixture of different components, following a pre-established formulation. The dosage of the raw materials can be carried out by different systems, namely by gravity through the continuous fluidization of the material, a worm screw with frequency controller and volumetric dosage through a rotary valve. The weighing of the different components is performed within one of the three weighing hoppers.

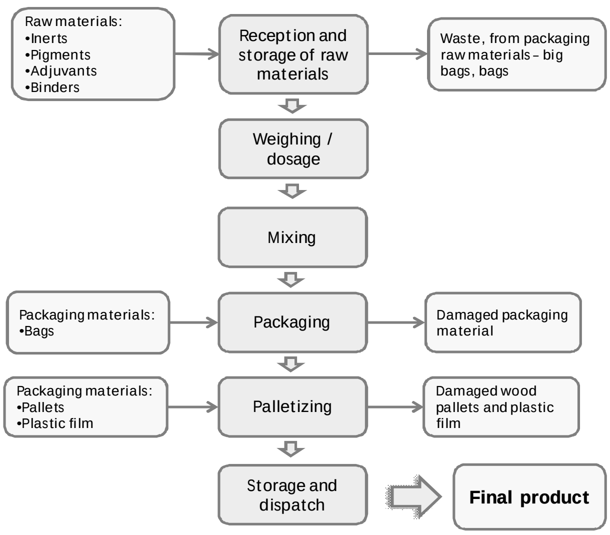


Figure 4. Mortar products production

Once dosed the components are discharged into the empty blender through pneumatic valves for homogenization. The mixing time varies depending on the specific composition of the product. After this, the product falls into the hopper of the blender and is then discharged.

The last stage consists in packing and palletizing the product. Regarding powders products, they are packed in bags through electric equipment and then placed on a pallet (palletized). Finally, the pallet and bags are wrapped in a plastic film and covered with a plastic bag.

4.2 *Module A4: Transport to the construction site*

To support the modeling of the construction scenario it was made a demonstration of the installation of the product on the premises of Saint-Gobain Weber, in Carregado Plant. For this scenario, it was considered that all the products would be transported from their respective production units to Carregado.

4.3 *Module A5: Installation*

The application of the system consists mainly in 6 stages, from fixing the aluminum profile to application of the final coating (Figure 5). To model this application, it was made a demonstration of the installation of one system in a wall with the dimensions 2,72m x 2,20m. With this procedure it was possible to understand the amount of products, energy and water used in the process and the eventual production of waste and wastewater.

The first stage consists in fixing the aluminum profile Weber.therm start. This profile has the dual function of aiding the system's assembly (keeping it horizontal and ensuring the support of the insulation boards), and also to assure protection against the penetration of moisture and external damage.

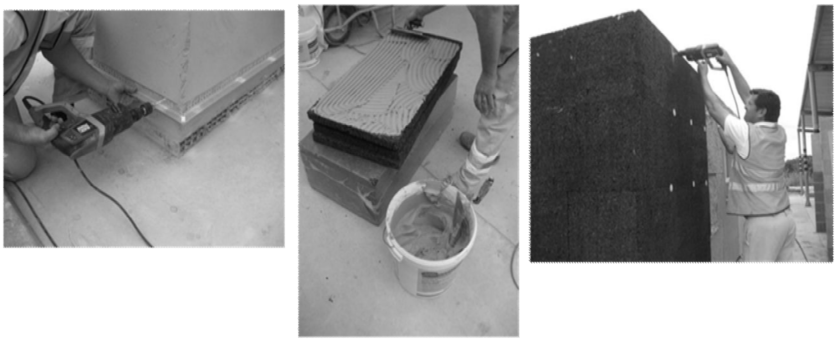


Figure 5. Screwing the aluminum profile, application of Weber.therm Naturcork and fixing insulation boards

This stage is followed by the installation of insulation boards that are glued to the wall with cement mortar Weber.therm Naturcork. The insulation boards are then fixed with plastic screws Weber Therm SPIT, usually 6 per m^2 of wall. The coating of insulation boards will be made with the application of mortar Weber.therm Naturcork in, at least, two layers, incorporating a reinforcement fiber glass mesh (Weber.therm Normal mesh). Final coating will contribute to waterproofing, protection and decoration and it is used Weber.rev Naturkal, using a stainless steel trowel, according to the desired appearance.

5 LIFE CYCLE IMPACT ASSESSMENT

The results of the Life Cycle Assessment are expressed into 6 impact categories through characterization factors, using the method CML 2012. These impact categories are:

- Global Warming Potential (GWP)
- Depletion Potential of the Stratospheric Ozone Layer (ODP)
- Acidification Potential of land and water (AP)
- Eutrophication Potential (EP)
- Photochemical Ozone Creation Potential (POCP)
- Potential for abiotic depletion of resources – elements for non-fossil resources (ADPE)
- Potential for abiotic depletion of resources – fossil fuels (ADPF)

5.1 *Global analysis*

Figure 6 shows the global impacts of the ETICS system from module A1 to A5.

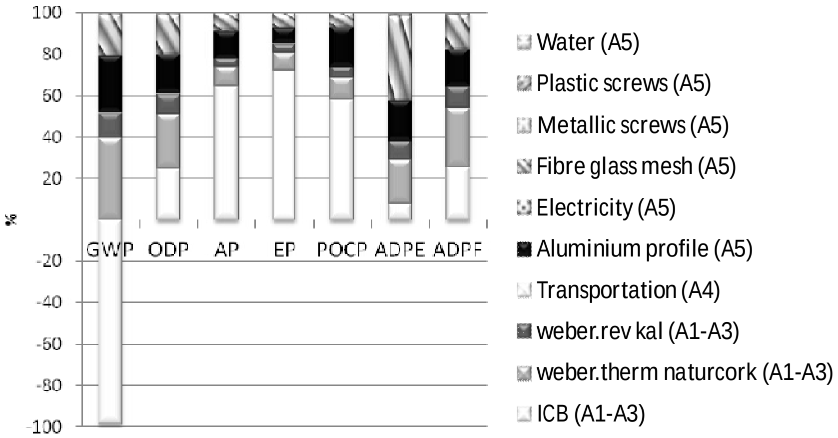


Figure 6. Impact assessment: module A1-A3, A4 and A5

Regarding the GWP category, ICB is the component with lowest impacts and actually a positive impact, due to carbon dioxide fixation. In this category, Weber.therm Naturcork has the highest impacts due to the production of hydraulic lime, cement and the polymer. The impacts associated with the aluminum profile and fiber glass mesh are linked to the use of electricity and other fossil fuels' combustion.

ODP category is affected almost equally by ICB, Weber.therm Naturcork, the aluminum profile and the fiber glass mesh. In all cases, the pollutants resulting from the combustion of fossil fuels are the main contribution for this potential effect.

The potential impacts in AP, EP and POCP categories are greatly due to the emission of pollutants during the production of thermal energy and electricity.

Category of ADPE is mostly affected by the use of the fiberglass mesh, associated to the production of nylon 66.

Impacts on ADPF category are almost equally due to the use of ICB, Weber.Therm Naturcork, aluminum profile and the fiberglass mesh. These potential impacts are all associated to consumption of energy from combustion of fossil fuels.

5.2 *Module A1-A3*

The potential impacts of the production stage A1-A3, which are the one with higher impacts, are indicated in Figure 7, in percentages of impacts per component.

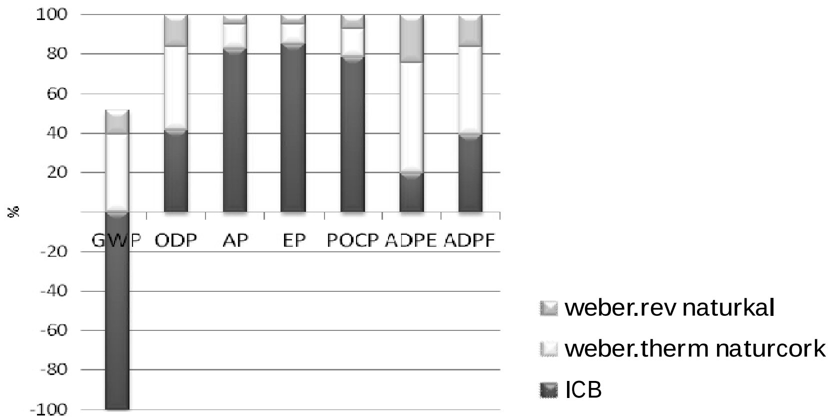


Figure 7. Impact assessment: module A1-A3.

From the results, it should be emphasized the global positive impact in the category of GWP. This occurs due to the use of cork that contributes to fixation of carbon dioxide during photosynthesis. The negative impacts are associated to the use of the mortar products. Production of clinker and hydraulic lime are the processes that represent the most significant negative impacts in this category, due to the emission of pollutants during combustion of fossil fuels to produce energy.

Results also indicate that an improvement of the system performance includes the need to work on both cork board and mortars associated. Related to ICB, in order to minimize the energy impact, it is possible to adopt strategies to reduce the emission of pollutants into the atmosphere. Currently, it is possible to reduce the emission of nitrogen oxides (NOx) by different technologies, namely:

- Selective catalytic reduction, using ammonia vapor to convert nitric oxide to free nitrogen and water using a catalyst bed
- Selective non-catalytic reduction, where ammonia or urea is injected in to the high temperature zone of the flue gas forming also water, nitrogen and in case of urea, carbon dioxide
- Oxidation catalysts, where several pollutants like NOx, CO and hydrocarbons are oxidized.

Carbon monoxide control can also be made by using an oxidation catalyst, although there are specific operating conditions to use this technology.

On the other hand, considering mortars and impact of the main binder (Portland cement or hydraulic lime) as the main factor to most of the impact factors, actions can be done to reduce their influence such as partial replacement by recycled material like slag or fly ash.

6 CONCLUSIONS

The LCA of Weber.therm Natura has led to the identification of the critical stages and components regarding the overall environmental performance of the product. With this information it is possible to develop goals and strategies of improvement that can range from the substitution of materials, changes in production processes and optimization of the transport operations of the various components to the building site. As we can see from the global chart, the product analyzed has almost null impact in global warming due to the use of ICB as an insulation material. Cork is a natural product from the cork oak which contributes to the sequestration of about 4.8 million tons of CO_2 per year, about 5% of emissions of Portugal (Corticeira Amorim). This contribution is extremely beneficial since the reduction of the greenhouse effect continues to be one of the greatest challenges to human activity. On the other hand, as we can see by looking at the results, the impacts associated with the production of thermal energy from burning cork still have a very significant impact on other impact categories.

Regarding mortars contribution, is visible their higher impact even if using binders as hydraulic lime, which demystifies a common myth related to the use of this binders.

The main issue for both materials is that is possible to continue focus actions in order to minimize the impacts. So, is clearly recommendable a continuous work on the presented recommendations, checking the improvements on LCA analysis.

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Chapter 12

Thematic Session - Smart Regions: which strategies?

Energy Performance Certificate: a valuable tool for building-to-grid interaction?

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ABSTRACT: New challenges were opened with the recast of Energy Performance of Buildings Directive, requiring by 2020 that new buildings be "nearly Zero-Energy Buildings" (nearly ZEB). In addition to consumer buildings, Net ZEBs are also producers' by using as much renewable energy sources as possible to compensate the building energy load. Sustainable cities require energy-efficient buildings, i.e. buildings where the use of energy is minimized without compromising the occupants comfort, namely for heating, cooling, lighting and indoor air quality. But smart cities require energy-efficient 'interactive' buildings, which integrate multiple-carrier energy networks and provide up-to-date valuable information for their management, where buildings are simplified to single nodes characterized by their energy load, generation, storage and conversion, applying the load-generation approach. The information currently available in the Energy Performance Certificate is not relevant for estimating the time dependent building energy load, but it can be easily improved by including a few descriptive parameters.

1 INTRODUCTION

New challenges were opened with the recast of the Energy Performance of Buildings Directive, (EPBD-Recast, 2010), requiring by 2020 that new buildings be "nearly Zero-Energy Buildings" (nearly ZEB). But, for some of European Member States, nearly ZEB are not defined in detail. Therefore, a more consistent definition is the Net ZEB (Sartori et al., 2011), intended as on-grid ZEB's, meaning 'buildings connected to the grid' delivering as much energy to the supply grids as they use from the grids (Laudsten, 2008). Net ZEB's are energy producer buildings besides consumers and, therefore, they use as much renewable energy sources (RES) as possible to compensate the energy requirements of the building.

Sustainable cities require energy-efficient buildings, i.e. buildings where the use of energy is minimized without compromising the occupants comfort standards, namely for heating, cooling, lighting and indoor air quality. In order to increase the overall energy efficiency in cities and facilitate the integration of RES into urban energy networks, building-to-grid interaction should be reinforced, requiring, from the buildings' perspective, energy-efficient 'interactive' buildings (EeIB). Henceforth, EeIBs actively interact with multiple-carrier energy networks (e.g. electric grid, thermal network, gas pipelines) by providing up-to-date information, valuable for the energy networks management. Therefore, not only energy flows, from or to an EeIB, are important, but also the information flows, based on accessing and predicting time-dependent energy flows. This is the context that frames the work here developed, following the objectives of EERA Joint Programme on Smart Cities (2011).

The energy networks modeling of Niemi et al. (2012) is an example of simulating multi-carrier energy networks including renewable energy generation, where buildings are simplified to nodes in the grid. In the load-generation approach (Sartori et al., 2011), buildings are evaluated by their energy demand (consumption or *load*) and energy supply (production or *genera-*

tion). But for energy networks modeling, energy *storage* potential should also be taken into account. It is noteworthy that in the Niemi et al. (2012) approach, geospatial and temporal loads data are required for running simulations, but they used instead an empirical simplified method to generate those data.

In European countries, building energy labeling was launched through Directive on Energy Performance of Buildings (EPBD, 2002), which attributed an energy performance scale to buildings. However, despite that, the Energy Performance Certificate (EPC) contains much more information about the building itself and energy systems, constituting the "identification card" of the building.

This paper aims at evaluating how relevant are the parameters available at EPC for residential buildings, considering the Portuguese example, for estimating the time-dependent building energy load required for multi-carrier energy networks modeling. Henceforth, the energy generation and storage are out of the scope of this paper, even if these terms are included in the formulation.

2 BUILDING-TO-GRID INTERACTION

2.1 *Building: Load-Generation-Storage-Conversion*

For modeling purposes, buildings are simplified to single nodes characterized by load (L), generation (G), storage (S) and conversion (C). It is noteworthy that the load-generation approach (Sartori et al., 2011) assumes as object boundary the building itself and, therefore, all the energy locally produced (generation term) and used in the building is included in its energy load. This consideration is different from the assumed by CEN/TR 15615 (European Committee for Standardization, 2008), where the energy produced on-site is deduced from the energy demand and delivered energy.

Since the design of the building is strictly connected to passive strategies/systems, such as solar heating, passive cooling or natural ventilation, for example a south oriented window is a direct gain system, the energy load is the energy required for heating, cooling, lighting, ventilation, etc. considering the use of all passive strategies/systems. The building energy storage is conceptually different from the natural building thermal capacity, which is included as a passive strategy; it identifies all forms of controlled storage of the energy carrier, such as hot water or ice tanks, for heat, and batteries, for electricity.

Load, generation, storage and conversion (Figure 1) apply to different energy carriers, *i*, and vary with time, *t*, so they are generically represented as $L_i(t)$, $G_i(t)$, $S_i(t)$ and $C_i(t)$, respectively. $L_i(t)$ and $G_i(t)$ are always positive, even if when they refer to 'cooling'. $S_i(t)$ can either be negative (for charge) or positive (for discharge). $C_i(t)$ takes negative values for the energy carriers that are used in the conversion and positive otherwise.

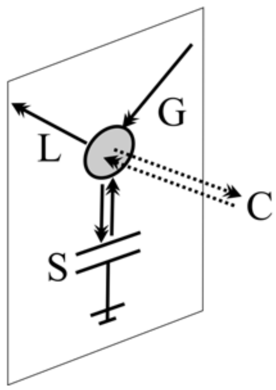

Figure 1. Building single-node representation: Load-Generation-Storage-Conversion

The energy systems of the building convert energy carriers into each other. The $C_i(t)$ term is the conversion energy balance for each energy carrier *i*:

$$C_i(t) = \sum_{k \neq i} c_{ki}/\eta_{k \to i} - c_{ik} \tag{1}$$

where $\eta_{k\to i}$ is the conversion performance from energy carrier *k* to *i* and c_{ki} is the energy carrier *k* transformed into energy carrier *i*.

The overall energy balance of a single node, for each energy carrier *i*, corresponding to the delivered or exported energy if it is negative or positive, respectively, is calculated by:

$$\phi_i(t) = G_i(t) + S_i(t) + C_i(t) - L_i(t) \tag{2}$$

It is noteworthy that the on-grid Net ZEB, could be achieved by considering all energy carriers $\phi_i(t)$ and integrating over a period of time, so that the overall primary energy, Φ, calculated by Equation 3 should be zero.

$$\Phi = \sum_t \Phi(t) = \sum_t \sum_i w_i \phi_i(t) \tag{3}$$

The w_i in Equation 3 are the weighted primary energy indexes or factors.

Henceforth, the off-grid Net ZEB, i.e. not connected to the grid, should achieve the goal of zero energy balance for each time-step *t* ($\Phi(t) = 0$), by supplying its overall load with energy generation and/or energy stored, considering conversion among different energy carriers.

A final note about possible restrictions applied to different terms: i) when there is a physical conversion restriction (e.g. no system converting electricity into fuel) the null energy performance is assumed; ii) the terms S_i and c_{ki} can be lower or higher limited, for example, by the systems power and the $\eta_{k\to i}$ can be expressed as a function of c_{ki} and iii) the building energy load is different from zero only for electricity, heat and cool energy carriers.

It is noteworthy that, thermodynamically speaking, the heat energy carrier includes heating and cooling energy needs. However, considering that the conversion performance can be significantly different for the same system or even systems that provide heating or cooling are different, they are assumed as two separated energy carriers.

2.2 *Networks: energy carrier and information flows*

Buildings represented as single nodes are interconnected among them, or with energy connectors, e.g. transformers for electricity grid or heat substation (see squares in Figure 2). Commonly, energy networks correspond to different overlapping levels for each energy carrier, namely electricity, heat, cool and fuels, considering in the nodes the possibility of energy carrier conversion. For example, heating requirements can be supplied by energy systems with different energy carriers such as a heat pump, boiler or solar collector. This consideration is possible by including energy carrier networks connections (dashed lines in Figure 2).

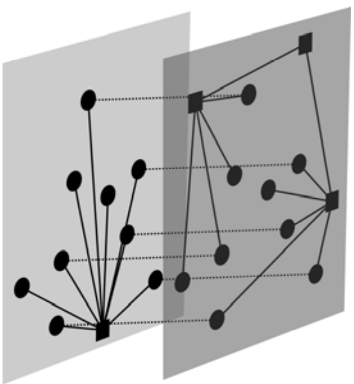

Figure 2. Two energy carrier networks connected by energy conversion.

For the energy network management, the knowledge of L, G, S, and C, which typically vary with time, is important. The smart management consists in deciding about the S energy flow (no use, charge or discharge), the C energy flow (conversion systems to be used) and grid interconnection energy flows.

3 BUILDING LOAD

3.1 *EPC data*

The building-to-grid representation requires the knowledge of the building load term, for a time-step considerably low, in order to provide valuable information for energy networks management.

For residential buildings, Portuguese EPC contains data of the thermal load for heating, cooling and domestic hot water (DHW) calculated for an annual time basis, which in the formulation here assumed are the time integrated L_1 and L_2, respectively, the heating energy load (space heating and DHW) and cooling energy load. Energy systems performance is also accessible from EPC, even if they are defined as constant values defined for nominal loads.

One of the requirements for building-to-grid interaction would be accessing time-dependent variables. Furthermore, the thermal loads are calculated for standard use conditions, which cannot be representative of the real use profiles.

The main conclusion of this brief analysis is that the current format of the EPC does not contain valuable data for building-to-grid interaction. Making the EPC a valuable tool for building-grid interaction is, therefore, the main goal of the following sections.

3.2 *Measuring and predicting*

In order to enable the use of EPC data, it would be required further information about the building itself. The main objective would be accessing the time-dependent energy loads, using a few descriptive parameters.

For heating and cooling energy needs, the method currently adopted in EPC is the quasi-steady state seasonal approach. However, the input data required to apply that method are very similar to other calculations methods, with different time-basis, such as the resistance-capacitance (RC) method of EN ISO 13790 (European Committee for Standardization and International Organization for Standardization, 2008), which is a simplified hourly method to compute heating and cooling energy needs. This method uses very few descriptive parameters of the building envelope (see Table 1). It is noteworthy that some of the variables required for running the method are user dependent, besides climate dependent. For example, the ventilation heat transfer coefficient varies with windows opening and/or ventilators use; effective solar collecting area varies with movable shading operation. The aforementioned variables could be included in EPC by defining the corresponding parameters related to each use operation profile, such as ventilators on and off, shading active and inactive.

The user plays an important role on the thermal energy loads, not only for the building main variables already discussed, but also for the real use of energy systems. That is why measuring data is complementary to EPC data, in order that user behavior be also taken into account in energy predictions.

The process of feeding the model with EPC and monitoring data enables to predict building thermal loads by taking into account the local weather forecast (climate data).

Table 1. Building envelope description for RC model.

Main variables	Total values	Specific values
Net floor area	A_f (m^2)	-
Transmission heat transfer coefficient for heavy elements (walls, roofs, floors, etc.)	$H_{tr,op}$ (W/K)	$H_{tr,op}/A_f$ (W/K.m^2)
Transmission heat transfer coefficient for light elements (windows, curtain walls, etc.)	$H_{tr,w}$ (W/K)	$H_{tr,w}/A_f$ (W/K.m^2)
Ventilation heat transfer coefficient	H_{ve} (W/K)	H_{ve}/A_f (W/K.m^2)
Internal thermal capacity	C_m (J/K)	C_m/A_f (J/K.m^2)
Effective solar collecting area by orientation	A_{sol} (m^2)	-

4 CASE-STUDY

4.1 *Description*

Assuming an apartment located in Lisbon, with 105 m^2 of net floor area, the transmission heat transfer per unit of floor area is 1.23 and 0.54 W/K.m^2, respectively, for heavy and light thermal capacity elements. The ventilation heat transfer takes an average value of 0.53 and 0.70 W/K.m^2, for winter and summer seasons, respectively. Internal thermal capacity is 260 MJ/K.m^2, corresponding to heavy thermal inertia. Effective solar collecting area for each one of the three orientations – north, south and west - is 3.31 m^2 only for windows glazing and 0.44 m^2 with shading devices. For a horizontal orientation the effective solar collecting area is 0.58 m^2, which is due to roof solar gains. For supplying heat to the apartment net floor area, a natural gas heat boiler with an efficiency of 0.89 is considered. Alternatively, a heat pump provides heating and cooling with 3.6 and 3.2, respectively, the equipment COP and EER. There are no local renewable energy sources or storage energy systems.

For the sake of simplicity DHW is not included in the case study. Heating season starts at November 29th and ends at May 6th, approximately 5.3 months. Cooling season lasts from June 1st to September 30th.

User profiles are defined as permanent heating/cooling during heating/cooling seasons. The activation of shading devices is assumed whenever façade solar irradiation exceeds 300 W/m^2.

4.2 *Results*

Running a simulation for one year, using 'Grande Lisboa' TMY (Aguiar et al., 2013), the hourly thermal loads for heating and cooling are plotted in Figure 2. Annual thermal loads are 17.1 and 10.9 kWh/m^2, respectively for space heating and cooling.

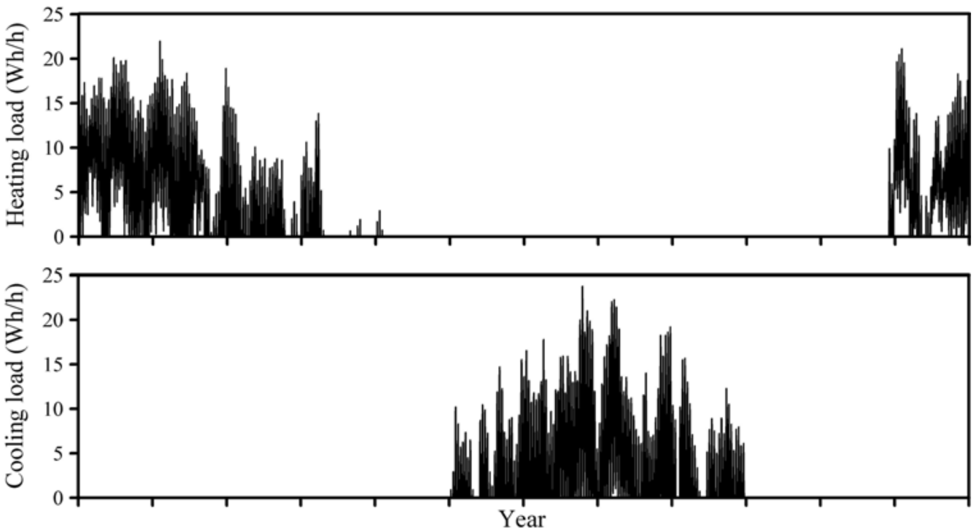

Figure 2. Thermal load for heating and cooling for the case study.

Regarding building-to-grid formulation, there are four energy carriers: 1) heat, 2) cool, 3) electricity and 4) natural gas. Systems energy performance assume the following values: $\eta_{3\to1} = 3.60$, $\eta_{3\to2} = 3.20$ and $\eta_{4\to1} = 0.89$. For each time-step and energy carrier, the energy balance is given by Equations 4 to 7.

$$\phi_1(t) = C_1(t) - L_1(t) = c_{31} + c_{41} - L_1(t) \tag{4}$$

$$\phi_2(t) = C_2(t) - L_2(t) = c_{32} - L_2(t) \tag{5}$$

$$\phi_3(t) = C_3(t) = -c_{31}/\eta_{3\to1} - c_{32}/\eta_{3\to2} \tag{6}$$

$$\phi_4(t) = C_4(t) = -c_{41}/\eta_{4\to1} \tag{7}$$

Since the building is neither connected to a thermal energy network, nor has local RES production, $\phi_1(t)$ and $\phi_2(t)$ should be null. Therefore, $L_2(t)$ is totally supplied by electricity conversion (heat pump). Otherwise, $L_1(t)$ is supplied by one or both of the systems using natural gas combustion (boiler) or electricity conversion (heat pump). The energy network management includes the decision about which heating system should be used by adopting decision criteria such as costs, avoiding peak electricity loads or, alternatively, using one of the systems as back-up whenever heating power exceeds the maximum thermal power of the main system.

For a scenario of solar collectors to produce heat, $G_1(t)$ and $S_1(t)$ would be alternatives for conventional energy systems, as Equation 8 shows. Henceforth, additional criteria should be defined, such as the priority of using heat from solar collectors or stored heat.

$$\phi_1(t) = G_1(t) + S_1(t) + C_1(t) - L_1(t) \quad (8)$$

The complexity would increase if the building with solar collectors is integrated in a thermal energy network. In this new scenario, besides heat and cool, there are no other energy carriers and $\phi_1(t)$ can assume positive values being a supplier to the heat energy network or negative being supplied from the energy network.

5 CONCLUSIONS

The current Portuguese EPC is oriented to give information about the building energy performance for an annual basis, which is not adapted for the required building-grid interaction. The main issue here discussed is how to achieve the time-dependent building thermal load by a few descriptive parameters, to be included in future versions of EPC.

The formulation for the multi-energy carrier networks is based on the Niemi et al. (2012) approach, but adapted in order to evidence for the EPC main object: the building. Its versatility allows considering different options for the management of energy networks: minimizing costs or primary energy, prioritizing RES, etc. Furthermore, the formulation is also very adapted for the on-grid NEB concept, since the primary energy integrated over a period of time, typically one year, but it can be higher (e.g. building lifetime) or lower (e.g. month), which should be null for those buildings, is a direct output of the energy networks modeling.

Finally, it is noteworthy that this study is still exploratory. Given that building-grid formulation is defined and the essential building parameters are chosen, it should be tested with multi-carrier energy networks, which constitutes future work.

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Smart battery management systems: towards an efficient integration of electrical energy storage in smart regions

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ABSTRACT: Electrical energy storage systems for electric vehicles or stationary applications will be important actors in Smart Region's energy scenarios, strongly contributing to increase the efficient and sustainable use of available resources. However, massive integration of such systems still poses many problems, requiring enhancements in batteries' life time, autonomy, reliability and cost. The development of new smart and accurate battery management systems able to communicate with a broad range of smart devices and energy management systems, to account with users' needs and smart grid management directives, are essential to operate such battery based energy storage systems, improving their overall performance. The paper discusses some of the technological developments needed in this domain and the requirements of smart battery management systems to comply with, presenting a modular hardware platform, developed at LNEG, as an example of the required structure and functionalities, relevant both in electrical mobility and decentralized smart-grid energy storage systems.

1 INTRODUCTION

New Smart Region's and Smart Building development scenarios are closely related with the efficient, sustainable and integrated use of available energy resources, considering that energy is increasingly scarcer and can´t be misused or wasted. Recent data shows that the built environment, mainly in cities or developed regions, has a relevant share of the global energy consumption and in the production of gases with climate impact, representing about 40% of the energy world-wide total consumption. This shows the necessity of thinking new ways to optimize the regions built environment energy usage, as a key contribution to decrease the global energy consumption and improve energy efficiency, both as consumers and producers (Meeus, 2010).

With new coming smart-grid architectures, energy storage systems are being pointed out as important technologies to help solving many of the current issues with the increasing grid's integration of renewable sources of energy, like wind or photovoltaic systems, contributing for their more efficient use and for more efficient and flexible management of energy demand (Ruester, 2012) (EASE/EERA, 2012) (Espinar, 2011).

This paper discusses the role, technologies and contributions of energy storage systems, namely those based on electrical batteries, in the context of Smart Regions and Sustainable Buildings, focusing the analysis in two main applications domains: electric vehicles (EV's) and decentralized stationary electric energy storage systems (SEES) for buildings or final users. In these contexts, new smart battery interface and management systems (Smart BMS) are considered to be the key enabling systems to the mass deployment and integration of these energy storage devices into smart grids and micro-grids. The development of a modular hardware platform, currently undertaken at LNEG, will be presented as an example of a development tool leading to future smart BMS's, using this hardware/software infrastructure to obtain the required devices with advanced functionalities to be applied both in electrical mobility and decentralized smart-grid energy storage systems.

2 ENERGY STORAGE SYSTEMS IN SMART REGIONS CONTEXTS

Public policies have been leading to an increasing penetration of non-fossil energy sources into the distribution grids. Nevertheless there are still some drawbacks to overcome with the proficient usage of these energy sources, mainly concerning the variability and intermittence of their availability, which causes significant mismatches between the more intensive energy demand phases and the periods when these kinds of energy are available. So, this integration requires a flexible and efficient balance of energy production and demand, regarding demand peak shaving, load shifting, and renewable resources variability compensation (Meeus, 2010).

Short term energy variability, mainly due to fluctuations of natural resources but also resulting from unpredictable small scale demand changes, are already addressed, in some extent, by energy producers and operators of distribution grids, by installing electric energy storage systems in energy plants or substations, in order to supply the missing power during short periods of time (Eurelectric, 2012) (Ruester, 2012) (Espinar, 2011) (Rastler, 2010).

However, medium term grid's stability and efficiency can also profit from the gradual penetration and adoption of local electrical storage systems, at several other levels (cities, small communities, buildings, etc.), decreasing the need of other expensive investments at the grid level (with high environmental impacts) and also lowering integration risks and costs.

For smart regions and smart buildings, the goal of achieving almost null energy balances is generally done by introducing local production based on renewable energy sources. This compensates or balances the energy consumption from the grid over a considered period of time (generally during one year), but requires solving new challenges in the design, construction and operation of these kinds of buildings. It also requires innovative energy management systems, namely including some kind of integration of local energy storage devices and EV's batteries as well as distributed stationary electric energy storage systems, which have been pointed out as being key technologies for this purpose (Ruester, 2012).

In the case of electric mobility, there is a progressively increasing variety of vehicles, from small 4 or 2 wheeled ones till private or public transportation vehicles. It is aimed that these vehicles can supply a large amount of energy stored in their batteries using Vehicle-to-Grid (V2G) integration solutions and technologies, allowing a more flexible management of the energy production and demand from the grid distribution point of view.

On the stationary side, applications can also be scaled from smart cities or communities, to buildings or down to the final energy consumers. Local electrical energy storage devices can store energy when it is not needed (from local generation or from grid at lower rates, taking profit, directly, from energy tariff differentiation offered by utilities) and discharge it when necessary. If their costs are affordable, they will support individual customers to reduce energy bills, constituting an important tool to modify energy consumption profiles and to manage consumption and eventual local production, at a domestic level.

Both stationary batteries and electrical vehicles, fully integrated within local Home Intelligent Energy Management Systems, will be determinant to enhance the environmental performance of buildings and communities (Figure 1).

Nowadays, there is a strong effort of research and technology development of electric energy storage systems, mainly focused in electrochemical devices but also in super capacitors, based on new materials allowing higher power and energy densities.

Lithium-ion (Li-ion) multi-cell batteries, offering high energy and power density, have become, in the recent years, the most important electrical storage technology, mostly due to its applications in the areas of portable and mobile applications (laptops, cell phones, small electric vehicles, etc.). However, these batteries can also be modular and scalable, making them suitable both for mobility applications, with different kinds of electrical vehicles with different energy supply needs, and for the stationary cases, with different levels of energy storage capacity needs, from the distribution level to the end-user (Fuchs, 2012).

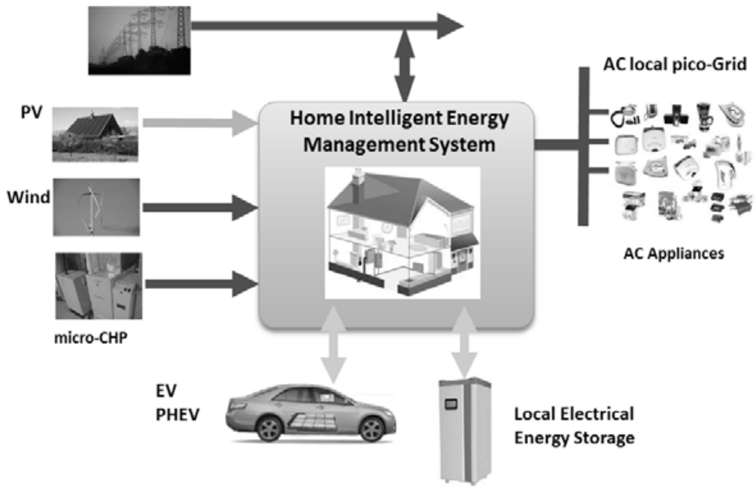

Figure 1. Energy storage systems within smart energy sustainable buildings.

Presently, the massive market penetration of EV’s is very much dependent on the confidence of users on the battery systems performance, regarding its autonomy, life cycle and costs. From the electrical grid point of view, there are also constrains that should be considered to prevent grid’s congestions faults and power strengthening needs, in order to accommodate the predicted increase in energy demand, caused by EV’s charging. Concepts like “smart charging” (grid controlled) and V2G can help the electric vehicles to cope with the grid operation, but these strategies may collide with the best use of EV’s batteries, forcing them to charge/discharge frequently in a partial way, causing its early aging.

In stationary applications the concept of smart charging still applies but V2G turns now into Battery-to-Grid (B2G), with benefits in terms of the range of selectable batteries and related algorithms and systems to control their operations. SEES can also accomplish all the roles intended for EV’s, regarding grid’s variability compensation and energetic efficiency, presenting advantages in terms of optimization of load management /demand response and peak shaving.

3 MAIN REQUIREMENTS OF SMART BATERY MANAGEMENT SYSTEMS

For electrical energy storage systems being largely spread, either for mobility or stationary applications especially in the context of smart charging in V2G or B2G environments, there is a strong need of innovative and flexible management systems and electronic interfaces, which could offer these storage systems the proper functionalities, accuracy and communication capabilities at a reasonable cost.

Complex multi-cell battery electrical storage systems require electronic Battery Management Systems (BMS) which monitors and controls the charge and discharge processes of the several cells or modules within the battery pack. These management and control systems are vital to ensure the safe operation of the battery packs and to extend its life cycles (Lu, 2013).

Nowadays there is some offer of on-the-shelf BMS and some battery’s manufacturers integrate such OEM devices into their products. Despite that, development and research in new real-time battery’s state-of-charge (SoC) and state-of-health (SoH) optimized estimation methods and algorithms and cells’ active charge balancing hardware topologies and algorithms are still needed (Zhang, 2011). These subjects require advanced and accurate data acquisition modules and easily configurable data processing and control embedded systems. Either for EV or stationary applications, BMS for batteries working in smart environments require significant processing, memory and communication resources to fulfill, in real-time, a set of battery storage specifications and functionalities, which include (Lu, 2013):

- precise measurement of physical variables (cell voltages, currents and temperatures) to better estimate battery state and control the charge/discharge cycles;

- more accurate real-time algorithms to estimate the battery's state and to improve cells' charge balancing;
- supervision of charge/discharge operations, detecting and acting in emergency situations, to guarantee battery security and protection;
- advanced communications capabilities, to interconnect with other external devices and equipment (as smart chargers, local user's interfaces, vehicle's subsystems, energy management systems).

Flexible management systems, with affordable costs, must then be developed using modular and distributed multiprocessing architectures, profiting from a low cost but powerful processors range, available at the market.

Regarding communications, it will be vital to offer a range of different communication and networking technologies and various standard protocols will be required to interconnect these energy storage batteries to other systems and peripherals under different application scenarios. This will allow an easier system integration in the EV's local control environments, in smart energy management and supply infrastructures or to interface with the end users, for instance in smart buildings (Figure 2).

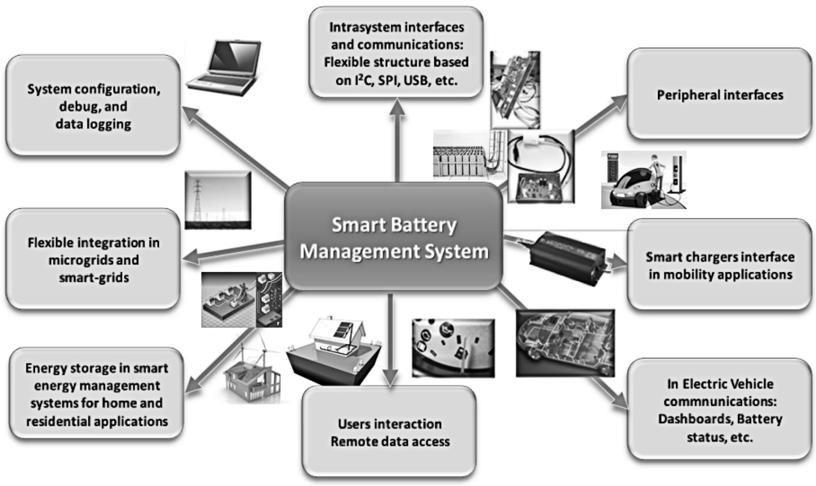

Figure 2. Smart Battery Management Systems communications interactions.

Another functionality these management systems must include is the local capability to control the charge balancing and equalization between cells of the battery pack. In multi-cell batteries, namely those with several Li-ion cells connected in series, the charge imbalance between cells is a relevant issue that can degrade the expected battery number of charge/discharge cycles (Einhorn, 2012) (Mizuno, 2012) (Zhang, 2011). Generally, the increasing number of charging/discharging cycles and ageing will intensify the cells' charge imbalance in a series-connected battery string and will decrease the total storage capacity and number of running cycles of the battery pack. So, keeping cells' charges at an equalized level is a very important issue for enhancing battery life which, itself, is an important concern for the end-users. Then, to optimize the overall pack running life, charge balance among cells, either in discharge or charge cycles, must be assured.

Several balancing or charge equalizer methods have been presented during the last years, both passive with charge dissipation and active using local charge re-distribution and balancing. Presently, there is a strong research effort in this domain, both to improve the algorithms and strategies of active methods and to lower equalization time and the costs of driving circuits. Another important aspect is to understand their consequences regarding battery life, as they imply additional charges and discharges, even if small, at cells' level. The efficient management of multi-cell batteries' charge and discharge cycles is also strongly dependent on the knowledge's accuracy of its cell's internal states, such as SoC, SoH and Depth-of-Discharge (DoD), which cannot be measured directly, during normal battery operation. Estimated values have to be used, determined by algorithms based on dynamic cell models, experimental data specific to the battery cell's type and on physical quantities measured from the battery pack (cell's voltages, currents, temperatures, etc.) (Rahimi, 2012) (He, 2012) (Tsai, 2012).

The majority of the existing cell models are mainly suited for simulation studies or for experimental offline testing, supported by powerful processing and memory resources, provided by up-to-date computational equipment. However, EV's and SEES' applications must rely on real time embedded electronic systems, which have more limited computational resources, to keep their costs at a low level. Besides that, the common existing models have not been developed having in mind the interactions that the battery based energy storage systems should stand in normal operation. In these systems, energy flow can change frequently in repetitive charge/discharge operations, causing partial charging-discharging cycles, with consequences on the performance and life time of batteries. Due to these new application scenarios, real-time estimation of batteries' internal states is nowadays a domain of competitive research, where the goal is to achieve lower complexity real-time embedded algorithms, without affecting accuracy and batteries information reliability. Available commercial BMS use proprietary algorithms, either for charge balancing or parameters estimation, making it difficult to embed new ones. Smart BMS must offer the possibility to include custom real-time estimation algorithms allowing reconfiguration and programmability to accommodate application dependent requirements.

4 MODULAR HARDWARE PLATFORM AND DEVELOPMENT FRAMEWORK FOR THE IMPLEMENTATION OF CUSTOM SMART BATTERY MANAGEMENT SYSTEMS

The previous considerations led to the development of a modular hardware platform, currently being implemented at LNEG, for the custom development of smart electronic microsystems for managing batteries operations, including the above mentioned structures and functionalities (Gano, 2012). This highly configurable and programmable structure supports the design of custom optimized real-time algorithms for cells' state estimation and for energy efficient cells' charge balancing subsystems, as well as flexible hardware/software integration. It is designed for battery packs with different Li-ion cell types and for different management infrastructures and devices, offering several hardware expansion possibilities (Figure 3).

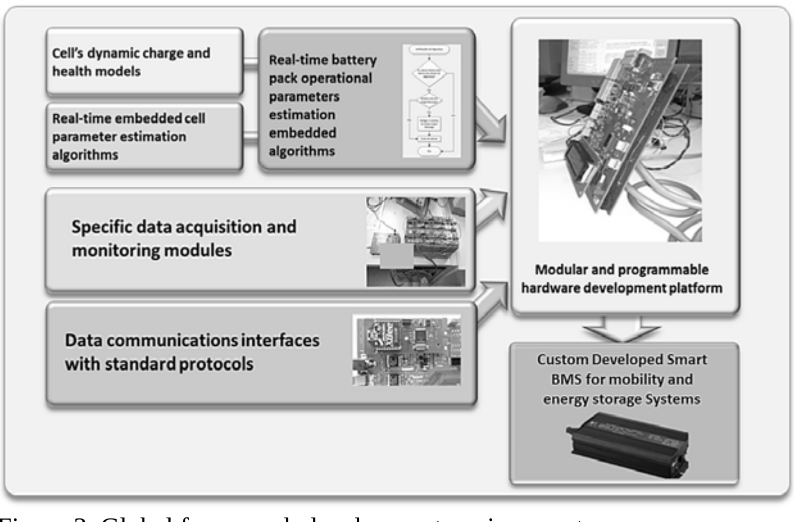

Figure 3. Global framework development environment

It is intended to be a useful development tool, leading to the design and implementation of pre-industrial custom prototypes of Smart BMS, to be applied both in electrical mobility and decentralized smart-grid energy storage systems, in the contexts of smart-grid integration and smart home energy management systems usage.

4.1 *System architecture*

The platform is based on two main subsystems with complementary functionalities: the cells' monitoring and balancing subsystem (with multiple modules) and the battery control and management subsystem for global data processing, local control and external interface (Figure 4).

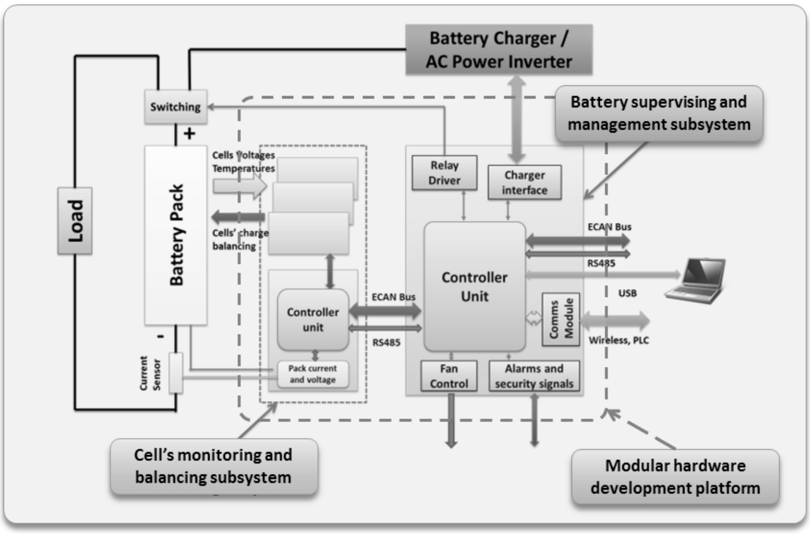

Figure 4. Global framework hardware architecture.

Each subsystem has a flexible configuration, allowing several interface and custom signal acquisition modules to be used for monitoring several battery physical variables. They include local control and actuation capabilities for processing both analogue and digital signals, using auto-ranging measuring circuits and calibration methods for improved accuracy.

The cells' monitoring and balancing subsystem is designed for real-time monitoring of each one of the pack individual cells' voltages, the battery pack distributed internal temperatures, the flowing current and the battery terminal's voltage. It is also able to control the individual cells' charge balancing process, including the possibility of using several charge balancing strategies, based on different electronic driving modules that are also under development. This will allow the test and evaluation of the actual performance of several balancing methods with respective driving circuits.

Currently, this subsystem can accommodate a maximum of 32 cells' monitoring modules, giving a maximum of a 192 Li-ion cells within the battery pack, each one with a nominal voltage between 1 and 5V. It has also its own local data processing unit, based on a 32 bit microcontroller, with local processing power for real-time estimation of main cells' functional parameters, like SoC and SoH. This subsystem can use different selectable methods to measure the battery pack flowing current using precision resistive shunts or Hall-effect sensors. The current measurement can range between 10 to 500A full scale, using programmable measuring ranges to optimize the resolution and the related measuring error. The total battery pack terminal's voltage is also measured using a resistive voltage divider, with programmable taps to optimize the accuracy for several measuring voltage ranges. There are 8 selectable voltage ranges between 10 and 1000V, to be selected accordingly to the total number and the nominal voltage of each cell within the respective battery pack.

The interface between the two hardware subsystems is made using the ECAN-Bus standard communications protocol, having an RS-485 serial port as an option. This interface has a galvanic isolation between both subsystems.

The other subsystem is responsible for the battery system's global management and control during charge and discharge phases. It controls the adequate battery connections' switching with external systems, making possible the battery pack isolation from external circuits in emergency cases or during stand-by, in addition to the battery's switching during the normal charging/discharging cycles. It also includes supplementary temperature measurement capabilities and driving electronics for battery global pack thermal monitoring and management, using specific fan controllers for preventing system thermal runaway.

This subsystem offers several standard interfaces and communication protocols to data interchange with external systems. As referred before, the development of smart battery management systems with enhanced communication capabilities is of major relevance in smart-grid application and integration contexts. This platform, offering several data communication ports with different communication technologies and standard protocols, will make it easier to interconnect the final developed smart battery management systems with other systems, within the smart-grid integration and the electrical mobility contexts. The main onboard external interfaces are again two ECAN-Bus 2.0 and serial RS485 ports, but one USB port is also available for direct interface with a host computer for system configuration, programming and data logging. Besides the above mentioned onboard communication ports, an expansion port for additional communication modules is available, giving the possibility of using wireless protocols (Bluetooth, ZigBee IP, WiFi, etc.) or Powerline Communications (PLC) standards, like the HomePlug Green PHY new standard. These expansion modules should have its own coprocessor for communication protocol stack handling and the local interface with the board main processor is made using standard UART, SPI or I^2C serial protocols.

In order to have direct control of the charging process, this subsystem interfaces directly with several types of chargers, using analogue or Pulse Width Modulated (PWM) signals or, in case of ‘smart’ chargers, the above mentioned ECAN Bus digital communications interface. The availability of several I/O expansion ports makes the integration of custom modules also possible, for instance, for electrical isolation monitoring and current leaks detection, improving this way the safety of the battery pack.

A graphical software interface for system configuration and data acquisition is also being developed, allowing an easier framework interface, both in terms of its hardware and firmware.

4.2 *System functionalities*

One of the goals of this development framework is to implement a library of algorithms and procedures for flexible and custom implementation of functionalities in the final smart battery management system, having in mind different applications and different cells’ technologies. As referred before, to fully manage the charge and discharge operations of a battery, a smart BMS needs to real-time measure and monitor several physical quantities in order to estimate some important parameters related with the state of the battery, as SoC and SoH, that cannot be measured directly during its normal operation. So, real time estimation of these variables can be a rather complex task, demanding configurable data processing resources and accurate algorithms which are still object of worldwide research efforts. Presently, most part of the existing commercial BMS systems don´t offer configuration or programming capabilities to test or integrate new developments or adaptations to these algorithms, paying attention to specific cells’ type or applications. However, this ability is one of the advantages to be offered by the present development framework, that can be used either to support experimental studies of cells and batteries models, in order to either develop and tune future algorithms, or to test and validate such algorithms to embed them in the system’s final firmware, having in mind specific mobility or stationary storage applications.

5 CONCLUSIONS

In smart cities and regions, sustainable strategies in the energy domain require a flexible and efficient balance of energy production and demand, regarding demand peak shaving, load shifting, and renewable resources variability compensation. This imposes a number of challenges in the design, construction and operation of buildings, demanding local advanced energy management systems with the integration of some kind of local energy storage devices.

Within these new energy management scenarios, electric vehicles and decentralized stationary energy storage are considered to be growing application areas for advanced batteries, mainly those based on Li-ion multi-cell packs, as electrical energy storage devices. For these systems being largely spread, either for mobility or stationary applications, innovative, flexible powerful embedded processing systems and electronic interfaces are required, offering these storage systems the proper functionalities, accuracy and communication capabilities at a reasonable cost, requested by smart environments.

The platform framework being implemented at LNEG, owns a set of characteristics (modular hardware/software architecture, multiprocessing, advanced communications, firmware libraries, etc.) which entitles it to be a powerful tool to support the design and development of such systems, leading to pre-industrial prototypes for a broad range of applications in the domain of EV or decentralized SEES. Its configurability, both in software and hardware, and programmability, will also allow to embed new software algorithms for management and control of batteries' operations, specifically developed and tuned for custom smart BMS.

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The nZEBs in the near Future
Overview of definitions and guidelines towardsexisting plans for increasing nZEBs

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ABSTRACT: Zero-energy performance buildings have gained significant attention since the publication in 2010 of the recast of the EPBD recast which requires all new buildings to become nearly zero-energy by 2020. Buildings are requested to meet higher levels of energy performance and to explore more the alternative energy supply systems available locally on a cost-efficiency basis. Since the directive does not specify minimum or maximum harmonized requirements as well as details of energy performance calculation framework, it is up to the member states to define the exact meaning of “high energy performance” and “amount of energy from renewable sources” according to their own local conditions and strategic interests. Nearly zero-energy building (nZEB) performance derives from net zero-energy concept (Net ZEB) which in case of buildings is usually defined as a high energy performance building that over a year is energy neutral. The successful implementation of such an ambitious target, however, needs to be planned out diligently. The critical steps are a) a correct picture about the existing state and trends, b) clear definitions and targets, c) dynamic building codes and energy efficient technologies and d) rules for testing and verification. The nZEBs or NetZEBs built in the near future therefore may play a critical role in implementing any ambitious plan as its success on long-term relies on setting best practice examples, in addition of the supporting policies and initiatives. The purpose of this paper is to review existing definitions, terms and policies on strategic planning of nZEBs at national and international level.

1 INTRODUCTION

Zero-energy performance buildings have gained more attention since the publication in 2010of the EPBD recast (EPBD, 2010). EPBD recast requests all new buildings to meet higher levels of performance than before, by exploring more thealternative energy supply systems available locally on a cost-efficiency basis and without prejudicing the comfort.To this end, beginning in 2020, all new buildings should become “nearly zero-energy”.A “nearly zero-energy building” refers to a high energy performance building of which annual primary energyconsumption is covered to a very significant extent by energy from renewable sources, including energy from renewablesources produced on-site or nearby.The directive requires nearly zero energy buildings, but it does not give minimum or maximum harmonized requirements as well as details of energy performance calculation framework. In such case, it is up to the Member States to define the exact meaning of energy performance requirements and percentage of energy from renewable sources according to local and regional climate and economic conditions. Recent studies on implementation on EPBD 2002 (Seppänen&Goeders 2010,Kurntsky et al. 2011) have shown a large variation in the building regulations ofthe different countries, a fact which has a significant impact on the building industry. Regarding existing concepts for nearly zero energy buildings, another study performed across 17 countries has revealed as much as 75 definition approaches and a single country with a definition included in national legislation (Hermelink et al. 2013). In the light of this, the need of a common approach on the concept for net and nearly zero energyis requested by the strategic importance of the building industry and by the need of MS to adapt their national plans in time in order to guarantee the implementation of the EPBD requirements by 2020 (…). Hence, on the basis of the above considerations, two important issues arise: nZEBs definition (article 2 of EPBD) and implementation of national plans for increasing nZEBS (article 9 of EPBD). This paper intends to unveil some of the key aspects related to the above issues, with a particular focus on the national policy context.

2 REVIEW OF EXISTING DEFINITIONS AND UNDERLYING PARAMETERS

Various experts have called attention on the problem various definition of nearly zero energy building may cause in Europe (Kurntsky et al. 2011). There is urgent need to answer questions such as: what are net / nearly zero-energy buildings and how are established the energy boundaries on the building, what energy flows should be considered in the balance calculation, what balance metric and weighting factors should be used in the calculation,what period of time should be considered to calculate the performance and how the energy generated and consumed should be accounted?

2.1 *Energy balance and Boundary*

If one draws an imaginary boundary in the nearby of a building (to account for renewable energy produced on-site and/or nearby), the energy balance may be schematically represented as in Figure 1. According to Figure 1, zero-energy buildings exchange energy with the grids (electricity, heating or cooling, gas or biomass)in the form of energy carriers thatis converted from or on to primary sources using credits. Accordingly, the energy balance, *EB*, for different energy carrier,*i*, between the energy delivered to building, *ED,* and the energy exported into the public grids, *EE*, writes:

$$EB = \sum_{i} EE_i \times fe,i - EDi \times fd,i \tag{1}$$

Where *f* are factors which are used to convert the physical units into other metrics, such as primary energy or equivalent carbon emission.

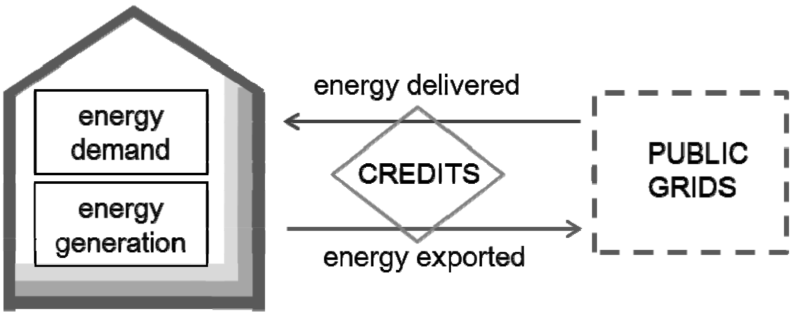

Figure 1. Schematic representation of energy balance of zero energy buildings.

Analyzing Equation 1, one can draw the conclusion that three different scenarios are possible, depending on the value of the energy balance. In the case of a neutral annual energy balance (i.e. the building use no more energy than it produce), the building is commonly referred as a NetZero-Energy Building. If the building falls short of the neutral balance then it can be referred to as a “nearly Zero Energy Building”. In the scenario where the balance is positive (when the building produces more energy than it consumes) the building is referred as a plus-energy building. The simple balance approach described so far becomes rapidly complex if one considers other features. For instance, if the boundary is drawn around a group of buildings instead (zero energy community), additional concerns regarding grids and conversion factors together with community-based infrastructure and industry need to be considered as well. In suchcase, it is possible that plus-energy buildings may provide the additional amount of energy to nearly zero energy buildings from the same community and contribute in this wayto the zero balance target of the entire community.

2.2 *Energy flows*

The boundary determines which energy flows are considered in the energy balance.While most of the building codes include energy use for heating, cooling, ventilation, hot water and lighting, recent proposals on definitions also include the plug loads and central services (e.g. appliances, elevators, fire protection systems) (Kurnitski et al. 2011, Atanasiu et al. 2011). Furthermore, some research projects also include the energy flows due to electric vehicles charging although these loads are not directly related to the building performance [B.u.S., 2011].Additionalcritical analyses on the energy balance reveal that in the above approach the energy inputs to deliver the building and its materials and components is not considered. Accounting for embodied energy (within its constituent materials and systems), can effectively serve as a form of 'net energy' analysis when compared to the energy used by the building in operation over the life cycle (Hernandez & Kenny, 2010). Studies on the life-cycle energy balance of low-energy and net zero-energy buildings indicate that the embodied energy of a typical building accounts for not more than 20 % of the total primary energy expenditure (Kugel, 2007).

2.3 *Weighting system*

Primary energy indicator sums up all delivered and exported energy into a single indicator using primary energy factors. Therefore, the metric of the energy balance should allow comparison of different forms of energy (electricity, natural gas,biomass and solid fuels). Using primary energy as an indicator raises a question concerning the conversion factors that should be applied (Voss et al. 2011). The averaged conversion factors may be either derived from actual national statistics or from European similar figures andthey are usually strategically determined in order to give priority to a particular category of energy fuel. A good example is the case of the asymmetrical weighting factors where the primary energy conversion factor for energy delivered by the grid is differentfrom the factor for energy exported into the grid to encourage on-site generation.In cases where carbon dioxide is considered appropriate, conversion factors from primary energy to carbon dioxide can also be considered. This approach provides additional information about the consequences of energy use, in the terms of CO_2 emitted to the atmosphere. However, due to the fact that carbon cycle has a strong dynamic character, accounting for emissions in the same context can be a tricky business (Black et al. 2010).

2.4 *Balance period*

The standard energy calculation procedure is annual due to need of accounting the whole range of operating energy of a building typical for a complete meteorological cycle. Climate plays a dual role in zero energy buildings (residential mainly) as it is a driver for space heating and cooling and a driver for supplying renewable energy resources at the same time.Using time intervals shorter than one year for calculus of the energy balance (seasonally, monthly or daily) is useful for the analysis of the interaction of the building with the electricity grid and other energy grids (Hermelink, 2013). According to recent studies (Hermelink, 2013) a yearly energy balance is not capable to provide the complete interaction with the grid as this procedure assumes the grid as an infinite storage. Buildings incorporating renewable energy systems are often characterized by a mismatch between the energy need and the energy generated on site. For instance, a seasonal calculus of the energy balance may result positive in summer (due to higher solar potential and lower energy needs) and negative in winter. As the consequences of mismatch are a matter under investigation perhaps the best strategy to adopt in this respect is to reduce the absolute value of the potential mismatch between demand and local generation (Voss et al., 2011). An effective way to reduce the mismatch is to reduce energy needs, a strategy which also provides advantages in terms of economic benefits (low energy buildings are significantly less prone to risks connected to volatility of costs/prices of conventional and renewable energy during their lifetime) and benefits associated to higher thermal comfort and user satisfaction (Hermelink, 2013).

Table 1. Definitions - renewable energy supply option (Marszal et al. 2011).

RES-footprint	RES-on site	RES-off site	
Use renewable energy sources available within the building's footprint.	Use renewable energy sources available at the building site.	Use renewable energy sources available off site to generate energy on site.	Purchase off-site renewable energy sources.

Table 2. Definitions (IEA, 2012).

Net ZEB limited	Net ZEB primary	Net ZEB strategic	Net ZEB emission
Weighted energy use for heating, DHW, cooling, ventilation, auxil-iaries and built-in lighting (for non-residential buildings only) vs. weighted energy supplied by on-site generation driven by on or off-site sources. Static and symmetric primary energy factors are possible.	Weighted energy use for heating, DHW, cooling, ventila-tion, auxiliaries and lighting and every kind of plug loads (electri-cal car possibly included), vs. weighted energy supplied by on-site generation driven by on- or off site sources. Static and symmetric primary energy factors.	Weighted energy use for heating, DHW, cooling, ventilation, auxiliaries, built-in lighting and every kind of plug loads vs. weighted energy supplied by on- and off-site generation systems driven by on- or off-site sources. Weighting factors could be static and asymmetric, varying on the basis of the energy carrier, the technology used as energy supply system and its location.	Balance between building CO2 equivalent emissions due to energy use for heating, DHW, cooling, ventilation, auxiliaries, built-in lighting, every kind of plug loads and the weighted energy supplied by on-site generation systems driven by on- or off-site sources. Static emission factors are used. They can be symmetric or asymmetric, depending on the energy carrier, technologies used as energy supply systems and their location.

Table 3. Related terms for definitions (Kurnitski et al. 2011).

buildingenergy performance (EN15316-1:2007)	delivered energy (EN15603:2008)	exported energy(EN15603:2008)	delivered energy (EN15603:2008)	system boundary (EN15603:2008)
Calculated or measured amount of energy delivered and exported actually used or estimated to meet the different needs associated with a standardized use of the building, which may include, inter alia, energy used for heating, cooling, ventilation, domestic hot water, lighting and appliances.	Energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (e.g. heating, cooling, ventilation, domestic hot water, lighting, appliances etc.) or to produce electricity.	Energy, expressed per energy carrier, delivered by the technical buildingsystems through the system boundary and used outside the system boundary.	Delivered minus exported energy, both expressed per energy carrier.Net delivered energy values are expressed separately for each energy carrier, i.e. for electricity, fuels, district heat, etc.	Boundary that includes within it all areas associated with the building (both inside and outside of the building) where energy is used or produced. All areas associated with the building typically refers to footprint of the building site.

2.5 *Definitions*

In an effort to synthesize many of the issues covered in previous sections, and assess the advantages and disadvantages of different strategies and scenarios of NetZEB definitions, and excel-based tool (NetZEB evaluator tool) was developed by a group of experts from IEA SHC Task 40 - ECBCS Annex 52 (IEA, 2008). The tool allows checking annual energy or emission balances as well as characterizing the load match and the grid interaction profile of a building by simplified indicators on the basis of four energy balance approaches (Table 2). As it can be seen from Table 1, four possible definition sets are proposed to allow detailed recommendations for future building codes in terms of a minimum of harmonization. After testing the NetZEB tool on seven buildings and their specific technical solution sets available in Task 40 database according to the four definitions, the authors have determined large differences between energy balance performances. They concluded that although all four balance procedures are conceivable in the frame of the EPBD it is very difficult to compare the resultsbetween each category. In spite of this difficulty, however, an important recommendation emerges from the study: the adoption of a definition for nearly zero-energy buildingson the basis of “Net ZEB limited” approach, as this methodology follows the minimum requirements in compliance with EU´s EPBD. For the uniform definition methodology, a general system boundary definition (Marszal et al., 2011) can be adopted as the guidance for technical meaning of “nearby” in the directive, as presented in Table 1. According to EPBD Annex 1, *The methodology for calculation the energy performance of buildings should take into account European standards*. A framework for energy performance calculation, including references to the definition of system boundaries, share of renewable is identified in EN 15603 as can be observed in Table 3.

3 NATIONAL PLANS FOR NEARLY ZERO ENERGY BUILDINGS

3.1 International guidelines

According to EPBD Article 9 Paragraph 3(a) the MS are asked to provide national plans for increasing the number of nearly zero-energy buildings. These national plans should include the requirements presented by at Paragraph 3(a), (b) and (c), namely, “national plans the inclusion (…) of the detailed application in practice of a definition of nearly zero-energy buildings, which reflects the national, regional or local conditions, and including a numerical indicator of primary energy use expressed in kWh/m² per year”, as well as intermediate targets and information about the policies and financial or other measures towards increasing the number of nZEB.In this respect, a recent work published by ECOFYS [Hermelink 2013] presents a set of guidelines for the implementation in the national plans the steps for increasing the number of nZEBs.

These strategic guidelines are drawn up on the basis of a consistent part of existing nZEB definitions, EPBD requirements and national energy strategic plans (National Energy Efficiency Action Plans or NEEAP and National Renewable Energy Action Plans, or NREAPs). Figure 2 summarizes the key parameters of NEAAPs and NREAPs together with the EPBD relevant requirements in the context of the nearly zero energy concept.

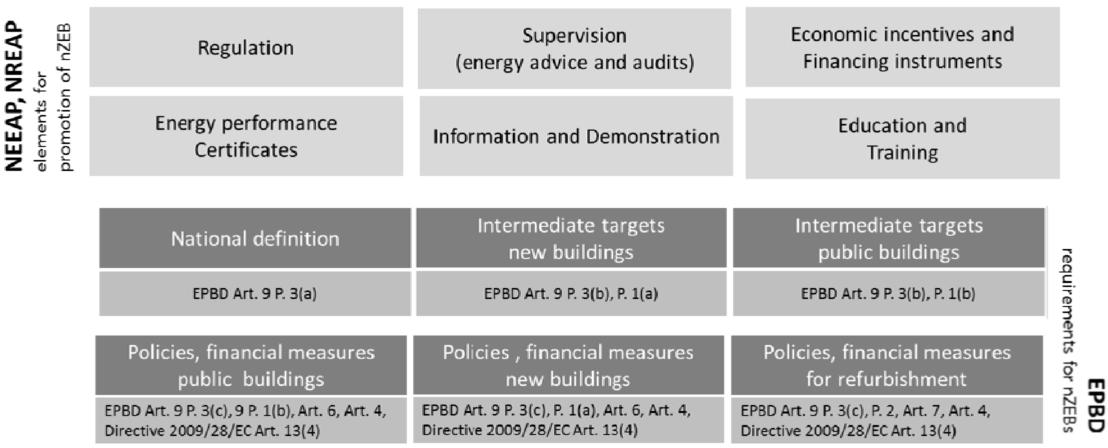

Figure 2. Key parameters of NEEAP/NEAPR together with EPBD requirements on plans for increasing the number of nearly zero-energy buildings

The above set of parameters is the basis of guidelines of a study performed among 12 European countries which were asked to provide information of the existing plans according to each parameter. This overview was useful in order to bridge the understanding between the existing national strategic plans (NEEAP and NREAP) and EPBD requirements based on the categories shown in Table 4.

According to the same study the intermediate targets should be explained in both qualitative and quantitative ways. The qualitative 2015 targets should be focused on energy related requirements for new buildings (including public buildings) and in this context specifically determine requirements on the fraction of renewable energies, the useful energy demand and the primary energy demand. The quantitative 2015 targets, on the other hand, should have a reference to the aimed share of new (and) public nearly zero-energy buildings according to official national nearly zero-energy building definition.

3.2 National situation point

The comprehensive overview of set of guidelines outlined in Table 4 provides valuable insights about the strategies to be considered in national plans. In the following, a general description of existing national plans is given, on the basis of the same strategic format proposed in Table 4.

Table 4.EPBD requirements on the national plans for increasing the number of nZEB

1) Definition	2) New buildings		3) Public buildings		4)Refurbishment
	2015 targets	2021 measures	2015 targets	2019 measures	nZEB measures
National definition of nearly zero-energy building, including a numerical indicator of primary energy use	Targets for new buildings on how to ensure that by December 2020, all new buildings are nZEB	Policies and financial or othermeasures to promote that by December 2020, all new buildings are nZEB	Targets for new buildings occupied and owned by public authorities to be nZEB by December 2018	Policies and financial or other measures to promote that by 2018, all buildings occupied and owned by public authorities to be nZEB	Policies and financial measures for the transformation of buildings that are refurbished into nZEB

3.2.1 National targets (Intermediate and 2020) for improved energy performance of new and existing buildings undergoing major renovation existing in PNAEE2016 and PNAER2020

The recently published National Energy Efficiency Action Plan (PNAEE2016, 2013) presents a list of programs and sub-programs that integrate targets and measures to improve the buildings energy performance including the new buildings, public buildings. These programs and the corresponding targets are listed in Table 5.

Table 5.PNAEE2016 targets.

Program	Accumulated Energy savings (tep)		CO2 emissions reduction (tCO2)	
	2016	2020	2016	2020
Residential and service Buildings	320.932	582.727	1.400.941	2.543.735
Government Energy Efficiency in Public Buildings	112.170	253.988	489.647	1.108.715
Behaviour - Information and communication of energy efficiency	-	-	-	-

Regarding the National Renewable Energy Action Plan (PNAER2020, 2013), the program of the use of renewables for heating and cooling sets for 2020 an increasing of 9% compared with 2010 taken as reference; with the major contribute of solar thermal and biomass.The total renewable energy use for heating, cooling and transport predicted for 2016 and 2020 is 5.259ktep and 5.737ktep, respectively.

3.2.2 Elements of policy packages for the promotion of nearly zero-energy building (new and existing buildings undergoing major renovation)

a) Regulation

No definition of nearly zero-energy building performance standard available. The new regulation for building energy performance calculation will be available in 2013 (for residential and non-residential buildings). Beginning with 2006, the installation of solar thermal collectors is mandatory for all new buildings according with the building regulation. (RCCTE, 2006).

b) Economic incentives and financing instruments

According with PNAEE 2020 the following incentives and financial instruments will be offered: Energy Efficiency Fund (FEE), Innovation Support Fund (FAI), Strategic Energy Efficiency Plan for promoting energy efficiency in the industrial, retail, residential and services sectors (PPEC), Portuguese Carbon Fund (FPC), National Strategic Framework (QREN), Joint European Support for Sustainable Investment in City Areas (JESSICA)

c) Energy performance certificates

The certificates for nearly zero energy buildings are not yet available. According with the PNAEE 2016 and with the revision of former PNAEE, the program Building Energy Efficient System increase the buildings energy performance through energy certificates by applying the requirements of the building regulation. This program will be reviewed after publication of the new building regulation.

d) Supervision (energy advice and audits)

One of the objectives of the PNAEE2016 for 2020 is to certificate a total of 2225 public buildings. 550 of these buildings will be covered by Eco-innovation Action Plan –EcoAP, thathas as principal objective to improve of energy efficiency in public buildings by means of monitoring and audits and is expected an energy savings of these buildings in about 30%.

e) Information and Demonstration

The program EcoAP is assisted by the initiative Barometer of Energy Efficiency in Public Buildings (Barómetro da EficiênciaEnergéticanaAdministraçãoPública) which has as objective a continuous divulgation of the energy efficiency and audits results. Later on will be promoted a Guide of Energy Efficiency of Public Buildings (Guia da EficiênciaEnergéticanaAdministraçãoPública).

f) Education and training

Trainings on building energy performance regulation have been developed by various institutions (universities and research institutes) in order to prepare experts leading and performing energy certification of buildings residential and non-residential.

4 CONCLUSIONS

National roadmaps towards nZEBs are needed for all member states. Member States shall draw up national plans for increasing the number of nZEBs that shall include, inter alia, the following elements: (a) detailed application in practice of the definition of nZEB, (b) intermediate targets for improving the energy performance of new buildings by 2015, (c) information on the policies and financial or other measures adopted in the context of for the promotion of nZEBs. Rather than disseminating specific results of the ongoing research developed under various frameworks, the authors of the present paper intended to bring into focus some insights of the existing definition and terms as the basis of the implementing national roadmaps towards increasing the number of nZEBstogether with the strategic guidelines drawn up on the basis of a consistent part of existing nZEB definitions. Regarding the national situation, the existing national strategic plans (PNAEE2016 and PNAER2020) are consistent with the strategic guidelines set out by EPBD for increasing the number of nZEBs. However, the successful of such an ambitious target depends greatly on definitions andenergy performance calculation and demonstration methods which are not yet available.

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Nudging Residential Consumers to Save and/or Defer Energy Consumption

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ABSTRACT: A smart meter as an energy management device is expected to help reduce and/or defer consumer power demand by providing real-time consumption and pricing information to residential users.On the other hand a growing number of empirical studies find that while knowledge is important, it is insufficient to initiate behavioural engagement. This project aims to contribute to a better understanding, from the perspective of consumer behaviour studies, of how energy is consumed domestically.In this project, energy consumption is collected every 3minutesover a period of two typical weeks across 60 households living in the Greater Taipei District, Taiwan, for three types of appliances that are identified as ones that use the most of stand-by power.

1 DOES PRICE PERSUADE ENERGY CONSUMPTION BEHAVIOUR?

There is an international call to all global citizens to preserve energyby reducing carbon emissions andusingenergy more efficiently.While generating renewable energy and increasing energy efficiency, many regard the end consumers as a vital player in the energy market and expect them to use less energy and more wisely. World Economic Forum (2010) recently put a call to place individual behaviour change as a prerequisite to achieving the energy conservation goals.There is an emerging consensus amongst experts that technology alone may not be sufficient to achieve the sustainability targets given the current scale of technological innovation and implementation (e.g. Bows et al. 2006). Also the 2020 targetmight remain unfulfilled if people use energy-efficient appliances more often and/or carelessly (Berkhout et al. 2001).

Many policymakers and economists use price-based strategies with the hope that extra monetary costs can increase a person’s sense of relevancy to energy saving and therefore lower energy consumption.Thus the chances may increase for people to be coerced into saving energy for reasonsof self-interest like cost saving. Nevertheless, the expectation that consumption and pricing information alone can trigger consumers to use energy more cautiously may underestimate the complexity of consumer behaviour and its underlying rationale.In fact, the act to be environmentally friendly involves more than simply weighing the costs and benefits.According to social psychology theories, factors such as moral concerns, risk factors like social rejection and self-image may also have effect on such decisions.

Electricity operates at the level of sub-consciousness within a home (Darby, 2010), and its importance is deeply felt when the level of comfort is jeopardised for energy saving (i.e. no air conditioning in mid-summer). Even more when the physical and psychological costs become too high to save energy (i.e. too hot to bear), people may respond more insensitively to price increase.Additionally, considering that energy costs usually account for only a small fraction of a fixed monthly expense, compared to for example house mortgage and insurance, consumers may not be as engaged and sensitive to price changes as expected.Lower-income householders may be more sensitive to price change (Darby, 2010); yet they are less likely to neither contribute significantly to energy consumption nor need to cut down their use of electricity.

This research intends to probe in detail the energy consumption patterns across various domestic appliances and how the consumers' perception of costs may relate to their actual use of energy.This paper starts with a brief review of studies in consumer energy consumption.It is followed by an introduction of the project method and ends with analyses of preliminary research results.

2 PSYCHOLOGY AND ENERGY CONSUMPTION

It is important to understand which factors promote or inhibit environmentally friendly behaviours.Various studies started from the assumption that individuals make rational decisions, weighing the expected costs and benefits of different actions and making choices most beneficial or least costly to them (Jackson 2005).The principle of such theoretical perspective is that in order to weigh the costs and benefits, consumers need sufficient information to facilitate their decision making.A smart meter can play the role as an information provider.Nevertheless this stream of thoughts failed to account for other arguably equally influential factors like moral concerns.

Several models and theories about behaviour change have been developed in sociopsychology.Various scholars have integrated concepts and variables from different theoretical frameworks, showing that behaviours result from multiple motivations (e.g. Lindenberg and Steg 2007).In other words, studies from social psychology suggest that disrupting the balance between the benefits and the costs would be insufficient to trigger behaviours.For instance, our behaviour in many cases is habitual and guided by automated cognitive processes, rather than being preceded by reasoning.This is particularly important with energy consumption behaviours which in many cases are based on routines (Martiskainen 2007).Three types of factors, internal, external and habitual factors, have beenidentified and proved to be predictive (Steg and Vlek 2009).

3 PROJECT DESIGN AND RESEARCH METHODOLOGY

Electricity is an unusual kind of product because it is invisible and cannot be stored cheaply or in great quantities.Demand for electricity varies depending on the time of day, day of the week and the time of year.Electricity consumption is therefore not perceived as a coherent field of action.Rather it involves activities as diverse as listening to music or working on the computer.In each of these activities, energy saving means a different set of behavioural modifications.It is difficult for consumers to link all these various activities and develop a coherent, comprehensible and concise cognitive frame of what "energy saving" could mean in their everyday life.Managing demand for power could play a critical role in the transition to a low carbon economy.Usually the goal of energy demand management is to encourage consumers to defer their electricity demand from peak hours to off-peak times such as night time, or to reduce their overall consumption for power (Ofgem, 2010).Keeping in mind the goal of energy consumption deferral, this project intends to start with understanding how energy is used domestically.

Sixty participants living in the Greater Taipei Area, Taiwan are selected on a voluntary basis through snow-ball sampling method.A measuring device (www.insnergy.com) which wirelessly collects energy consumption every 3-minute interval are installed in these households for more than two typical weeks.Broadly speaking two types of data, behavioural and psychological, are collected.Behavioural data refers to the amount of energy used for three selected household goods: a TV, a washing machine and an electric thermal kettle.They represent three broad groups of domestic electrical appliances: brown goods, white goods and small appliances.They are identified as appliances that use the most stand-by powerin Taiwanese households.

The psychological data are collected to measure the behaviour antecedents.Respondents are asked to rate their opinions about various aspects of "costs" when conducting energy saving behaviours.They are graded using a 7-point Likert-type rating scale (1= Extremely Disagree to 7 = Extremely Agree).The statements and the descriptive statistics are summaried in Table

1.Respondents are also asked to indicate the typical hours when there are no or little human activities at home (i.e. sleep hours and work hours).

4 DATA RESULTS AND IMPLICATIONS

In general the respondents do not think the costs identified in the questionnaire are crucial as the means for most items are graded below the scale median, 4.When examining the categories of costs, the actual expenses and their sense of confidence to save energy are considered more important than other costs like social rejection and self-image.This may indicate that they consider combating climate change a part of their responsibility and energy saving is one measure they can take.Out of all items the only one with average over the scale median is, “It may not be as effective as I imaged”.This shows that the effectiveness of energy saving is considered one major reason that may influence their decision making.

Table 1 Preliminary data analysis result: mean and standard deviation for each item

Expenses	Mean	SD
It would end up costing me more	2.96	1.34
It would be a lot of trouble	3.04	1.29
It would compromise my personal comfort	3.29	1.64
I can’t be bothered	2.31	1.11
It may not be as effective as I imagined	4.17	1.65
I may break the appliances	2.91	1.60

Social Rejection	Mean	SD
Why should I if no one else is doing it?	1.97	0.98
I might seem less approachable	2.60	1.34

Self-Image	Mean	SD
I would feel less guilty in other occasions when I waste energy	3.69	1.72
It would not fit in with my life-style	2.25	1.05
I don't think climate change will impact on my life	2.16	1.49
I don't think it's any of my business	2.07	1.13

Self Confidence	Mean	SD
It is not easy to do	3.70	1.88
I don't think my contribution can make any impact to save the planet	2.91	1.30
I find it difficult to reduce my energy use	2.93	1.31
I don't feel I have enough knowledge to make well-informed decisions on environmental issues	3.64	1.58

It is expected that the respondents who place less emphasis on costs, would be unlikely to use less power when there is low household activity, vice versa.The top 4 respondents with the least scores in the overall cost scale are respondent 20, 14, 16, and 12, respectively.Their average consumption on a typical Monday are summarised in Figure 1 and the hours when there is low household activity (sleeping and out at work hours) are marked orange.The top 2 respondents who score highest on the overall cost scale are respondent 53 and 3, and their consumption patterns are summarised in Figure 2.

Amongst the three appliances, electrical thermal kettles apparently consume the most power. It is an electric kettle which boils water and maintains the water at 90~95°C whenever it is plugged in. By 2010 their stand-by power alone consumes more than 2.2 billion kWh each year (EPA Taiwan 2010). Even though the kettle is plugged in at all times, the consumption patterns for respondent 20 and 14 do not seem to fluctuate as much as that for respondent 16 and 12. For the latter two respondents, their energy demand peaks when there is household activity and the stand-by power is a lot lower than the other two households. In relation to the energy use of washing machines, demand tends to be during off-peak hours except respondent 16. Out of the three appliances it is most feasible that a washing machine can be used during the off-peak hours in every household.

For respondents who consider costs an important element in their decision making, the consumption patterns similarly indicate a low level of consistency. Respondent 31 does not demand a lot of energy when there is low household activity and the appliances are used during the hours when there is more household activity. On the other hand the consumption level of respondent 53 remains constant for the electric kettle and the use of washing machine peaks during the day. Also, the TV uses more energy than the kettle and washing machine during the evening.

When examining the actual energy consumption of the respondents, the patterns appear to be inconsistent. The respondents' perception of costs, whether high or low, does not seem to reflect their actual consumption behaviour, which indicates that energy saving can be more complicated than simply considering costs.

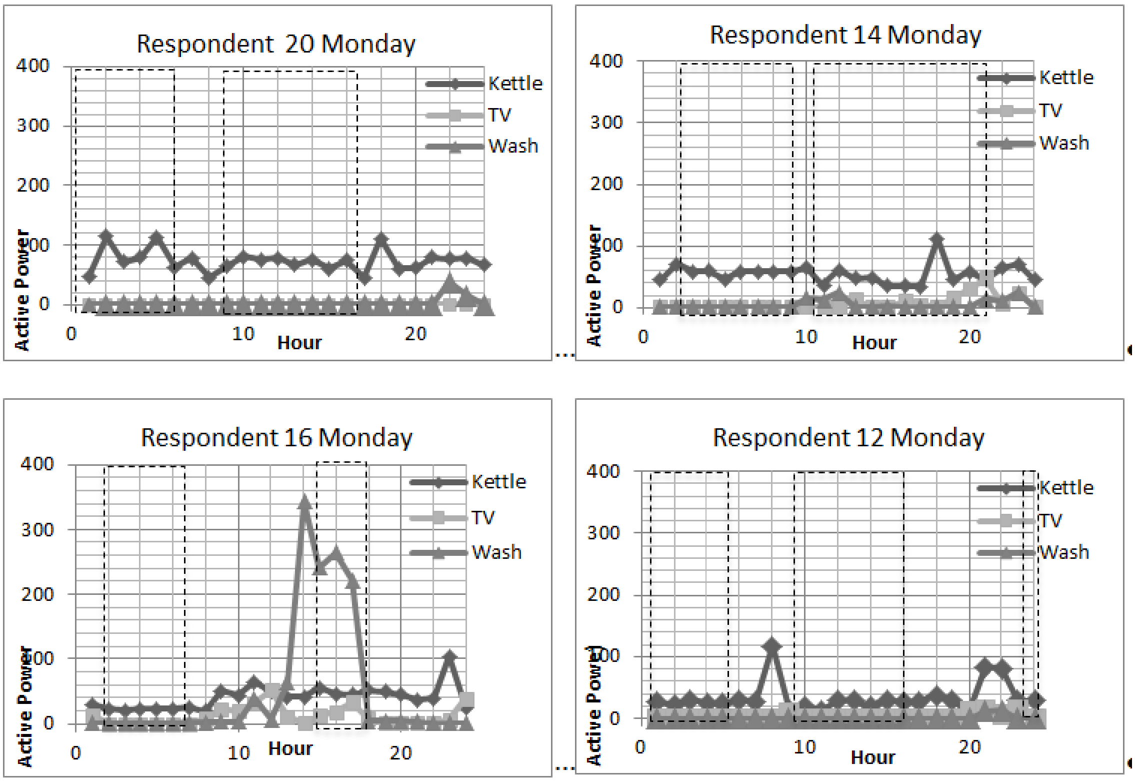

Figure 1 Consumption Patterns for 4 Respondents Least Worry about Costs

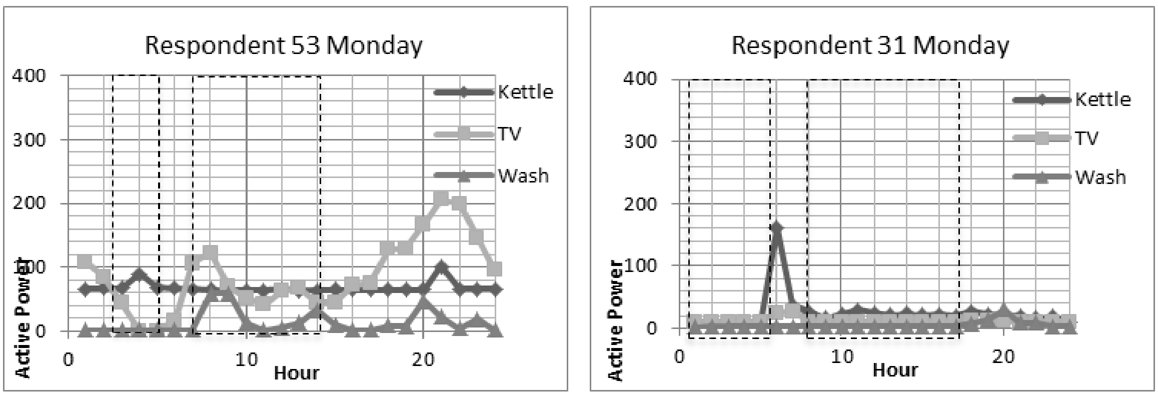

Figure 2 Consumption Patterns for 2 Respondents Most Worry about Costs

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Enabling Self-Healing Strategies in a Smart Grid Context

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ABSTRACT: This paper presents the reasoningunderlyingthe objectives of optimally deploy remotely operated switching devices (ROSDs) envisaging Self-Healing strategies. The deployment of ROSDs aims at decreasing the number of switching devices required to minimize the energy not supplied, i.e. increasing the quality of service provided by the distribution network operator. The appropriate allocation of ROSDs, along with bidirectional communications schemes, enables self-healing strategies in services restoration. It is mandatory to assess the cost/benefit for the ROSDs investment. Stability and reliability are expected to increase in the network as the electrical power shortages decrease. The research result is expected to help distribution Operators to increase their objectives tomodernizeof the network towards a "Smart Grid".

1 MOTIVATION FOR A SELF-HEALING STRATEGY

Electrical power shortage is a major concern in distribution networks. From the consumers' or the Distribution Network Operator's (DNO) perspective, interruptions cause major concerns related system stability and reliability. Economically speaking, interruptions result in concerns for what it may cost to compensate consumers, and to repair or to provide alternatives for power supply, as well as the fear, inconvenience and/or loss of leisure activities that are extremely difficult to assess due to their intangible natures (Billinton & Allan, 1996). Additionally, the Portuguese DNO faces penalties by not keeping quality of service (QoS) above certain standards. Hence, service restoration is required not only to reduce interruption costs and improve QoS, but to keep the network operating in stable conditions (Aguero, 2012).

In 2012the total energy not supplied by the Portuguese DNO reached3900 MWh due to more than 25,000 interruptions in the medium voltage distribution network and the compensation paid reached more than €90,000(EDP Distribuição, 2012). In addition to their compensation, a lot more should be added including the costs of repair or maintenance, losses of customers affected, loss of QoS, among others immeasurable costs.

The incidents in the electrical system cannot be directly avoided; however, an efficient, rapid isolation of the faulted power element and consequent restoration of the service to the costumers takes a key role in reducing the directly and indirectly cost associated with those power interruptions.

2 SELF-HEALING STATEGY

Self-healing of power delivery system is a concept that enables the identification and isolation of faulted systems components following the restoration of energy delivered to customers. This activity may be conducted with little or no human intervention and has the objective of minimizing service interruption and thus avoiding further deterioration of system reliability index. Self-healing of power distribution systems is conducted via Distribution Automation (DA) specifically through smart protective and switching devices that minimize the number of interrupted customers during contingency conditions by automatically isolating faulted components and transferring customers to a different power supply when their current supply is lost. Optional sources may include neighboring feeders and Distributed Energy Resources (DER) such as Distributed Generation (DG) and Distributed Energy Storage (DES) (Aguero, 2012) (Bensley, Grommesh, & Stemborg, 2011) (Bingyin, Mengyou, & Spitzer, 2010).

Implementation of self-healing in distribution systems requires strategies that are flexible enough to adapt to changing system loadings and configuration conditions and operate distribution system components within their technical ratings. Distribution Automation (DA) is a set of technologies that enable an electric utility to remotely monitor, coordinate, and operate distribution components in a real-time mode from remote locations. DA includes substation, feeder and customer automation. DA is a vital component for achieving the self-healing capabilities.

Self-healing strategies are an inherent part of the Smart Grid concept and are expected to play a fundamental role in modern and future distribution systems. It is worth noting that the switchgear technology (protective and switching devices), sensors, enterprise systems and communication infrastructures required for the implementation of self-healing strategies. Therefore a growing number of self-healing projects are being implemented by different network operators as part of their power delivery modernization plans: *Telegestore* in Italy (2005), *Hydro One* in Canada (2010), *MoMa* Project in Germany and *InovCity* in Portugal.

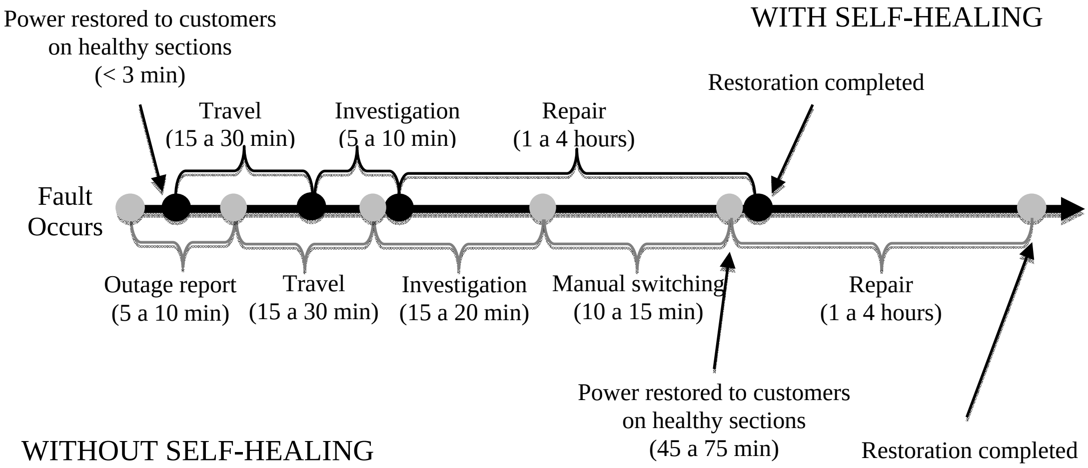

Figure 1.Comparison of reliability improvement between implementation of Self-Healing and conventional restoration(Aguero, 2012).

Without a self-healing strategy, there is a need to search for the specific fault location and conducting manually switches to isolate the faulted power element and then to restore service to the customers. Usually when the consumers contact the Network Operator about the existing power outage in their homes or work, the Network Operator sends out their staffs to locate the faulted power element and restore the power service. Figure 1 shows the time required between self-healing strategies and the conventional operation for a typical distribution feeder.

Nevertheless, there is a need to evaluate technically and economically the benefits achieved by deploying remotely operated switching devices (ROSDs) envisaging self-healing strategies. Costs that should be taken into account should include, such as, the cost of energy not supplied, reduction on the electricity sales during the interruption, customer compensations and regulatory penalties/benefits associated with the quality of service.

3 SUMMARY OF THE ADVANTAGES OF SELF-HEALING FOR THE UTILITY AND CUSTOMERS

In the following there is a summary of the advantages for implementing a self-healing strategy when seeing from the network operator's perspective and from the costumers' perspective:
From the utility perspective, expected benefits include: reducing energy not supplied; reducing fault investigation time; improving reliability statistics; achieving regulatory incentives; increasing revenue (sell more energy) and increasing labor/vehicle savings.

From the customers' perspective, the benefits are: reducing outage cost; reducing interruptions frequency; reducing interruptions duration, and improving the quality of energy supplied.

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Value materials and energy flow toward energy independence: agroforestry and urban biorefineries

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ABSTRACT: Portuguese energy independence has changed its paradigm in the last decade, with a strong focus on the different sources of renewable energy. However, the transport sector still has the greatest dependence on fossil fuels. This article presents a strategy to develop and optimize mass and energy flows towards energy independence from oil. The main strategy is based on the development of a network of integrated biorefineries (agroforestry and urban) for the development of smart regions. Biorefineries-to-Smart regions are a key option for energy independence. The average annual consumption of fuel in the transport sector in Portugal is 5 billion liters of fossil fuels. In 2010, economic and human activities in Portugal generated about 5.5 Mt of municipal wastes and 19.5 Mt of non-municipal wastes. Of these, 24.3 Mt present potential for integration into value chains in biorefineries, and may give rise to the production of 4.3 to 6.0 billion liters of biofuels. Portugal has a potential territorial valuation (wastes from 1.9 Mha of uncultivated land and wastelands, from 1.8-3.2 Mha of forest and agriculture) for the production of 1.6 to 2.3 billion liters of biofuels. The study also presents a sensitivity analysis of different scenarios of valorization of these mass flows into biofuels and biobased replacements for petroleum. The main conclusion that is Portugal has a potential to 71.8-99.9 % energy fossil independence, on based, to integrated agro-forest and urban mass flow.

1 INTRODUCTION

The European Union (EU) has made significant efforts during recent decades to position itself as a leader in environmental policy and promoting significantly the concept of sustainable development (SD) on the global scene (Vogler, 2003). Europe's environmental legislation is among the most advanced and progressive worldwide in a wide range of other areas (Falkner, 2007; Kelemen, 2010). The EU has been attempting to 'carry the SD flag on the international scene' since the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro (Lightfoot and Burchell, 2004). EU decided to proclaim sustainable development an official goal to be integrated in all EU policies and decision-making (Baker, 2006). SD was explicitly included - for the first time ever - as a fundamental objective in its relations with the wider world in the 1997 Amsterdam Treaty, as well as in its 2001 Nice and 2007 Lisbon successors, with the focus on the theme of 'green economy' and 'smart, sustainable and inclusive growth' (Rioþ20 and 'Europe 2020 Strategy') (Afionis and Stringer, 2012).

The use of biofuels in the European market is becoming an increasingly controversial policy area, with the scale of the planned expansion giving rise to serious concerns as to whether the 2009 Directive's 10 percent target can be met in a sustainable fashion, despite the criteria being the strictest worldwide to date. Ensuring sustainability involves balancing seemingly conflicting needs across what is known as 'The Three Dimensions of Sustainability' (Gomar and Stringer, 2011). All three aspects are equally important in terms of sustainability and a balancing approach is therefore a sine qua non. Prioritizing is not an option, as doing so, Blackburn (2007) argues, is like asking, ‘which is more important to human life: air, water, or food’?

Although biofuels/bioliquids that fail to meet sustainability criteria are not excluded from use, only biofuels/bioliquids that fulfill these criteria count towards the 2020 renewable energy target or are eligible for financial support. The sustainability criteria apply irrespective of the location where the feedstocks are cultivated (German and Schoneveld, 2012). Between 1997 and 2007, the EU-27's energetic dependency continued to grow, reaching 53,1% in 2007. In the same period, the final energy consumption in the EU-27 increased 5%, being that in 2007, the transportation sector was responsible for approximately 32% of that consumption. Road transportation is responsible for more than 80% of the energy consumed in this sector. In the EU, the transportation sector is responsible for about 19% of all gas emissions related to greenhouse effects (DGEG, 2013).

Portugal presented, in 2011, the following distribution of final energy per sector: 1) 35.8% in Transportation; 2) 33.7% in Industry; 3) 16.6% in Domestic; 4) 11.3% in Services; 5) 2.6% in Agriculture and Fishing (DGEG, 2013). Em 2011, the contribution of renewable energy in the total primary energy consumption was of 22.8% versus 23.4% in 2010 (with an exernal energetic dependency of 77.2%). It is notable the growth, in the last few years, of installed power in the renewable energy sources for electricity production. In 2011, we reached 10,622 MW of installed power, with 5,332MW in hydro, 4,378MW in wind, 711MW in biomass, 172MW in photovoltaic and 29 in geothermal. In 2011, 25.612GWh of electric energy were produced from renewable energy sources, representing a contribution of 36.2% to the overall consumption of electric energy. Portugal's external energetic dependence in the electric sector is being continuously solved, however the problem remains in the transportation sector. Despite the fact that Portugal is incorporating 1st generation biodiesel in the transportation sector, it mostly derives from imported raw materials from Africa and the Americas. In 2010 in Portugal, there were 7 large national producers and 30 small dedicated producers. In Portugal, companies that meet the following requirements are considered small dedicated producers: i) maximum annual production of 3.000 tons of biofuel or other renewable fuels; ii) using the residual materials or including technological development projects that produce less pollutent product, using innovative processes or in a demonstration stage; and iii) its production must be placed in the captive fleets and producers, properly identified.

In Resolution nº104/2006 of July 31, of the Council of Ministers of Portugal, which approved the National Program for Climate Change, PNAC-2006 (“Programa Nacional para as Alterações Climáticas, PNAC-2006”), the incorporation of 5.75% in energetic content, of biofuels in transportation was published as meta for 2010. In the meanwhile, the Resolution nº 1/2008 of the Council of Ministers, of January 4, the government decided to increase to 10% this goal of incorporating biofuels in the transportation sector (DGEG, 2013). In 2009, in the transportation sector, 256,282 tons of biodiesell were incorporated into gasoline, which represents an incorporation of 4.28% PetroDiesel in energy content. In all, the incorporation of biofuels in the transportation sector was of 3.32% in energy content. In terms of incentives, for the 2008-2010, the Portuguese legislation gave the larger producers of biodiesel an Petroleum products tax exemption of 280€/1000litres.

Biorefineries process bioresources such as forest, agriculture or urban biomass to produce energy and a wide variety of precursor chemicals and bio-based materials, similar to the modern petroleum refineries. This study presents the potential of biorefineries to convert agroforestry and urban residues into biofuels to increase energy independence in Portugal. The study is concentrated in agroforestry residues because the problems associated with the load fuel available in land that has high potential risk for forest fires, which is also potential for conversion into biofuels. The urban residues context is associated with inefficient technologies that exist in Portugal for the conversion of these resources. Network integrated agroforestry and urban biorefineries is the solution and pathway present is this paper for these problems. There are four main biorefineries: biosyngas-based refinery, pyrolysis-based refinery, hydrothermal-based refinery, and fermentation-based refinery. Biosyngas is a multifunctional intermediate for the production of materials, chemicals, transportation fuels, power, and/or heat from biomass, (Demirbas, 2009). The mass flow from agroforestry and urban activities is mainly a lignocelluloses resources. Lignocellulosic feedstocks for bioenergy and biomaterials production include forest residues, agricultural and horticultural residues, municipal solid waste, livestock manure, perennial grasses, bioenergy crops, aquatic plants, and paper and cotton wastes (Ruane et al., 2010; Ramachandra et al., 2000). Selection of feedstocks for biorefinery operations depends on several criteria like potential yield per hectare, adaptation to climate conditions, agricultural inputs required, biomass characteristics, and the potential uses (Fahd et al., 2012).

Forest fires are a major hazard in Mediterranean Europe, where an average of 45,000 fires occur per year (European Commission, 2011). The sustainable management of forests in Europe, which occupy nearly half of Europe’s total area (FOREST EUROPE, UNECE and FAO, 2011), requires the understanding of the factors that influence fire occurrence and its environmental and socio-economic consequences. The conditions for fire to occur can be assessed prior to the fire season, taking into consideration the structural factors which remain relatively stable during at least one fire season (San-Miguel-Ayanz et al., 2003), such as topography, climate and infrastructures (road density etc.), providing a long-term evaluation of the most fire-prone areas. The distribution of fire density is irregular. An extended cluster of fire densities reaching over 1.7 fires per km2 on average per year is prevalent in northern and central Portugal, and northwestern Spain. In the northern parts of France and Italy and some parts of Greece fires occurred rarely in the study period (Oliveira et al., 2012). In the study Oliveira et al., 2012 it´s evident that Portugal has a serious problem with fire forests and is the most affected in Europe.

In recent years, the quantity of urban waste has increased significantly in the EU and other industrialized and developing countries, Johannessen, 1996; Berenyi, 1996; Kilgroe, 1996; Wiles, 1996; Ruth, 1998; Otoma et al., 1997; Hunsicker et al., 1996). There are many questions regarding what is for the best pathway for treatment of this mass flow, raising the question of its sustainable disposal management. Urban wastes, in particular, Municipal Solid Waste can be treated by pyrolysis and gasification, and consequently integrated in biorefineries value chain. These technologies are very attractive, for they reduce and avoid corrosion and emissions by retaining alkali and heavy metals (except mercury and cadmium), sulphur and chlorine within the process residues, prevent largely the formation of Polychlorinated Dibenzo-p-Dioxine/-Furan and reducing the formation of thermal NOx due to lower temperatures and reducing conditions. Slagging gasification may additionally provide for destructing hazardous compounds and vitrification of various residues. However, Cl and S species such as HCl and H2S may still occur in the fuel gas yielded (Malkow, 2003). The Malkow, 2003 study presents a lot of references (more than 50) that verify pyrolsyis and gasification as a sustainable disposal management option, and that use this mass flow replacements from oil-based fuels. Pyrolysis and gasification integrated into the thermalchemical biorefineries platforms (biosyngas-based refinery and pyrolysis-based refinery), and are selected in this study for the potential independence energy analysis in Portugal.

2 PROBLEMS AND OPORTUNITIES FOR AGROFORESTRY AND URBAN BIOREFINERIES

2.1 *Management and forest planning; the forest fires paradigm*

Portugal, Spain, Italy, Greece and Turkey are European countries with a high percentage of soils without any use. In Portugal, the estimate is of about 34% (ICNF, 2013). In Portugal, areas without economic activity have been growing since 1995, due to the non-existence of value chains that value the exploration of territories with bushes and uncultivated land. In 1995, the unproductive areas in Portugal occupied 30.6% of the whole territory, with that number rising to 32.7% in 2005 and to 34.0% in 2010 (ICNF, 2013). These soils represent a problem to upkeep, and they are often prone to fire events (fuel load), which prevent continuous investment and their management. They are rich in natural vegetation that have high energetic value; plants are adapted to local climate conditions and they are resistant to disorders. It is an important territory that is in need of an industry that values its natural resources. Given its raw materials, namely lignocellulosic resources, biorefineries are an important value chain that might fix the problems of great fires in Portugal, whilst increasing the economic competitiveness and promoting rural development and energy independence.

2.2 *Valuing territories with rich native vegetation and forest residues*

These territories present different characteristics from ecosystems of wood production and energetic cultures (smaller density and productivity). Usually, they have poor soils and they were abandoned, as the alternatives are low value systems. This problem is often related to the logistic issue, i.e, the quantity of raw material collected per hectare and physical characteristics. E.g.: One hectare of Eucalyptus with 12 years (1st harvest) can represent an average collection of 220-250 tons in one operation (Nunes, 2008), whereas one hectare of spontaneous vegetation with 4 years (the best turnover assuming a sustainable rotation), may produce about 12-20 tons. Besides, 1 ton of hardwood or softwood has a density of 1050 to 1150 $kg.m^{-3}$ (fresh tissue), whereas the forest residues and native shrubs show a density of 250 to 330 $kg.m^3$ (Nunes, 2008). The actual systems of transport in Portugal present the following characteristics and limits: 24 – 26 tons, 77 m^3 or 15 tons and 54 to 60 m^3 for the lower dimension. One logistic problem suppresses the harvest of this type of materials, as they only produce a final added value of 0.30-0.32 $Euros.kg^{-1}$ for electricity and 0.02-0.45 $Euros.MJ^{-1}$ for thermic use in the Portuguese context (Nunes, 2008). It is necessary to develop a sustainable alternative of the valuation of territories with spontaneous vegetation and without agriculture aptitude and to develop economic activity for these territories. It is worth pointing out that these territories and raw materials have additional advantages as they do not compete with other economic activities, they do not need water or fertilizers, they are resistant to diseases and they don't imply costs of production. In addition, raw materials related to natural vegetation, typical after land abandonment, are not profitable, and they represent a great potential of valuation for 2nd generation biorefineries to produce biofuels and bioproducts, and to close the nutrients cycle in agroforestry sector.

2.3 *Problems related to the inefficiency and value of forest resources (conventional technologies)*

When the intention is to convert forest resources, it should be considered that we collect timber and water per unit of volume. Moreover, plants producing electricity with forest residues combustion show low levels of net efficiency: 17 to 21%, and they do not operate more than 7000 hours (a conclusion of the "*BioREFINA-Ter*" project - more information about this project is presented in point 2.5 and 4.3 - and results from the study presented in Nunes, 2008). As the commercial value of electricity is not high enough to cover the costs, and due to the inefficiency of this value chain, the demand for wood is tremendous, causing serious problems of competition with the transforming wood industries and promoting a deep unbalance in the activity. In Portugal, in the context of forestry and wood transforming industries residues, the following were observed for the production of electricity and/or heat from direct combustion (data collected by the author through forestry inventories done in the forestry sector): i) before December 31, 2009: 9 cogeneration power plants (336.9 MW) and 8 thermoelectric (111.0 MW), with total potential installed power of 447.9 MW; ii) after December 31, 2009: 0 cogeneration power plants (0 MW) and 3 thermoelectrical (5.3 MW), with a total potential installed power of 5.3 MW. In 2009, 15 public tenders for the licensing of injecting electricity into the Portuguese distribution network were launched, for a total of 100 MVA (DGEG, 2013). Of the 15 launched tenders, only 3 are working presently, due to questions relating to the lack of economic competitiveness associated with the conventional technologies (direct combustion), when applied in an industrial context. The costs associates with the collection, logistics and pre-treatment are fundamental for the levels of net efficiency that can be obtained. The BioREFINA-Ter project aims to develop one system that values more a hectare of forest and the unit of biomass of forest resources, making profitable the use of shrubs and other native plants and residues, and thus avoiding competition with the food and wood based industry.

2.4 *Treatment of effluents and ecosystems' contamination*

The treatment of effluents from the agriculture and food industries are usually only active technologies for the direct treatment of effluents, aiming only at cleaning the water at the end of the process, i.e. do not have the vision to value the constituents in the wastewater. In order to add environmental success, tertiary systems are included and they have noteworthy benefits. However, this investment can be less interesting in small-scale plants. On the other hand, it is difficult to close agriculture and food industries when they are essential for the social and economical development of some regions, and force the installation of expensive advanced technologies, very often without human and funding resources to support them. As an example, in a region with 25,000 inhabitants, in Portugal, where the BLC3 headquarters are located, and where the cheese industry has a strong socio-economical impact, 18 million litters of effluents are generated per year. 95% of which are not treated and they are simply discharged onto fertile soils and water sources, creating serious problems of contamination and euthropication. These values were obtained in 2010 based on an inventory made in all the cheese Oliveira do Hospital producers, in close collaboration with the City Hall of Oliveira do Hospital.

2.5 *SMART Regions: BioREFINA-Ter project innovations and strategy*

The present study presents a vision for valuing the mass and energy flows in the agro-forestry and urban territories, through a biorefinery system. In section 4, we present the potential of biorefineries for energetic independence in Portugal. BLC3 is developing a biorefinery project – BioREFINA-Ter - under the concept of "Smart Regions", with an emphasis on optimization and efficiency. BLC3 wants to promote the development of smart regions, with the integration of the agroforestry sector and urban and human activities. For that purpose, the BioREFINA-Ter project was designed to strengthen the use of inputs from various different economic activities, particularly unvalued ones (natural vegetation and agroforestry residues) and problematic ones (municipal solid wastes and agrifood industrial effluents). The BioREFINA-ter project focuses on the segment of the bioeconomy that uses renewable biological resources in innovative industrial processes for manufacturing biomass-derived goods/products and services. This project represents the development of a new biorefineries system with high energetic and environmental performances, under a concept of continuous microscale. It is particularly keen to integrate parts of the biorefinery process with other industrial processes in development, to actively promote competition between the production costs of biodiesel and other bioproducts, increasingly equating them with liquid petroleum-based fuels. System will bring a production capacity for 25 Mliters/year biofuels, with 82% bioenergy output. The most important target is to increase net energy efficiency, in terms of full life cycle, to 76-82%, and 178,6 gCO2eq/MJbiofuel avoided (reduction >100%), based on the concept of industrial symbiosis and intelligent control, simultaneously maximizing mass and energy flows. The desired social impacts are an improvement in skilled and unskilled employment of about 250-290 new jobs. The place where the demonstration plant will be installed is Oliveira do Hospital, serving an influence radius area that includes the councils of Gois, Arganil and Tábua - 103,043 hectares -, which have the following characteristics: 57% of the area is constantly generating forest waste, 25% is uncultivated land, and 14% is agricultural land. In terms lignocellulosic biomass that can be used for bioenergy production, this region has an average delivering capacity of 170,000-180,000 tons/year, without affecting any local economic activity. This huge amount of raw material can be transformed in 30-43 Mliters/year of biofuels. Regarding transportation combustibles, the energy dependence of this region is 100%, presenting a fossil primary energy requirement of 671*103 GJ/year. The energy balance in this pilot region, in vectors as electricity and heat, is now positive, exceeding 100% of renewable energy resources. The installation of the demonstration plant would change the current situation to a 100% renewable energy in transportation sector through the bioenergy value of chain (expected biofuel production of at least 850*103 GJ/year), consequently achieving an 100% RENEWABLE ENERRGY REGION. This project will be applied to a Portuguese case, but it can easily be replicated to other European countries, especially the Southern ones. This is due to the fact that Southern European countries have the same problems: forest fires, non-competitive territories, abandoned land and difficulty in attracting and fixating critical mass in the inner regions and rural development difficulties.

3 ENERGY AND MASS FLOW ANALYSIS IN PORTUGAL

3.1 *Agro-forest*

Portugal has a very significant soil occupancy regarding agro-forestry. In Table 1, the distribution by main existing ecosystems is presented (data by ICNF, 2013), which generate considerable amounts of lignocellulosic residues.

Table 1. Soil occupation by ecosystem in Portugal.

	1995		2005		2010	
	ha	% of Portuguese overall territory	ha	% of Portuguese overall territory	ha	% of Portuguese overall territory
Florestry*	3,305,411	37.1%	3,211,839	36.1%	3,154,800*	35.4%
Agriculture**	2,407,772	27.0%	2,205,124	24.8%	2,114,278	23.7%
Bushland, Pastures and Shrubland***	2,729,649	30.6%	2,916,119	32.7%	3,031,721	34.0%
Inland Waters	150,586	1.7%	176,867	2.0%	182,568	2.0%
Urban	315,475	3.5%	398,945	4.5%	425,526	4.8%

*of the 3.1 Mha, 57% are pinewoods, eucalyptus, other resinous trees and acacias (AFN, 2013), with only these being considered in the biorefineries context, given that they generate the most significant amount of residues. In the study, only 1.8 Mha will be considered.

**In the study, only agricultural land with production of lignocellulosic materials will be considered (olive groves, vineyards and fruticulture), in a total of 1.4 Mha.

*** Uncultivated land and wastelands represent 1.9 Mha.

Considering the productivity values obtained in certain studies (Nunes, 2008; Silva et. al, 2006; and project "BioREFINA-Ter"), in Table 2, the average productivity of lignocellulosic mass flows with the possibility of introduction in 2nd generation biorefineries is presented.

Table 2. Average annual productivity, on a dry base, of mass flows according to ecosystem function.

	2010		
	Mha	ton dry basis.year-1 (lignocellulosic resources)	Total Mt
Florestry	1.8	1.6	2.9
Agriculture	1.4	1.0	1.4
Bushland and Shrubland	1.9	2.5	4.8
Total	5.1	5.1	9.1

These resources are analyzed in section 4, in relation to their energetic conversion potential into 2nd generation biofuels.

3.2 *Urban*

According to Eurostat data (2013), in 2010, the economic and human activities in Portugal generated about 5.5 Mt of municipal wastes and 19.5 of non-municipal wastes. Of the total 26.4 Mt, 24.0 present potential for integration into value chains in biorefineries, since they are mostly lignocellulosic residues or residues that can be incorporated into the thermochemical reactors (biorefinery platform chosen for the present study).

4 POTENTIAL OF NETWORK INTEGRATED BIOREFINERIES FOR ENERGY INDEPENDENCE IN PORTUGAL

4.1 *Fossil fuels consumption*

In Table 3, the totals of fuels sold for transportation in 2009 are presented, by type of fuel. The mass consumption values were obtained by DGEG, 2013. The energetic conversion factors for each fuel type obtained are for the year 2009 (DGEG, 2013). Information regarding fuel consumption in transportation, divided by type, is only available up to 2009. However, fuel consumption has diminished significantly. At present, the average consumption stands at 5 billion litres/year of diesel fuel and gasoline.

Table 3. Fossil fuel consumption 2009 for transports sector in Portugal.

Type of fuel	Consumption	
	Mass ton or Nm3	Energy toe
Gasoline	1,452,823 ton	1,526,916
Diesel Fuel	5,170,886 ton	5,263,961
Liquefied petroleum gas	26,589 ton	29,211
Natural gas	15,301,000 Nm3	14,169
Total		6,834,257

4.2 *Potential energy independence*

The industrial symbioses are key aspects regarding the energetic independence, optimization and efficiency of biorefineries. According to point 3.1 and 3.2, Portugal generates approximately 33.4 Mt.year-1 of residues, which have potential to be transformed into liquid biofuels for transportation, based on 2nd generation technologies. A sensitivity analysis for independence from fossil energy in Portugal is presented below, for a biorefinery thermochemical platform, and with conversion rates spanning from 178 to 248 liters/ton dry basis (data from BioREFINA-Ter project).

Table 4. Sensitivity analysis towards independence fossil energy in Portugal.

Mass flow (ton.year-1)		Biofuels production Liters*103.year1-		Produção de biofuels toe.year1-		% of Energetic independence	
		Scenario A	Scenario B	Scenario A	Scenario B	Scenario A	Scenario B
Agro-forestry	9,100,000	1,619,800	2,256,800	1,336,229	1,861,712	19.6%	27.2%
Urban	24,300,000	4,325,400	6,026,400	3,568,171	4,971,384	52.2%	72.7%
Agro-forestry+Urban		5,945,200	8,283,200	4,904,400	6,833,096	71.8%	99.9%

*LHV (biofuels 2nd generation) = 44 GJ/ton; Density = 0,785 ton/m3; 6,834,257 toe fossil fuels consumption in transports.

Table 4 presents different scenarios for the valuation of the mass flows from the production of biofuels of 2nd generation. When the mass flows from the agro-forestry are joined with the urban sector, a possible energetic independence is reached.

5 CONCLUSIONS

Portugal has an energetic external dependency of approximately 76.6%. The electricity sector already has satisfactory levels of energetic independence, given the strategic investment in renewable energies in Portugal. However, the transportation sector in Portugal is almost 100% dependant on imports (fossil fuels and 1st generation biomass). The conventional technologies for the conversion of lignocellulosic resources, from the agro-forestry sector, into electricity, have reduced liquid efficiencies (17 to 21%), which contribute to the failure in implementing biomass centrals for electricity production in Portugal. Portugal has significant potential of mass flows: 9.1 Mt.year-1 in the agro-forestry sector and 24.3 Mt.year-1 from the urban and human activity sector. This unvalued high mass flow creates problems, such as forest fires, with Portugal being the single most affected EU country with this issue. In the 2nd generation biorefinery context in Portugal, the BioREFINA-Ter project is highlighted. In Portugal the average annual consumption of fuel in the transport sector in Portugal is of 5 billion liters of fossil fuels (6,834,257 toe). The integration of agro-forestry and urban territories is very important for the development of smart regions and towards to energy independence. This symbiosis can enable a level of energetic autonomy in the transportation sector from 71.8 to 99.9%.

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Author Index

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InnoMatNet is a 30 month project launched in April 2012, funded under the NMP (Nanosciences, nanotechnologies, materials and new production technologies) theme of the European Union 7th Framework Programme.

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+

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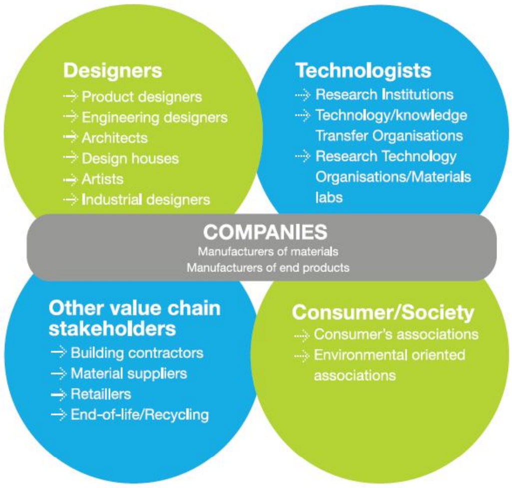

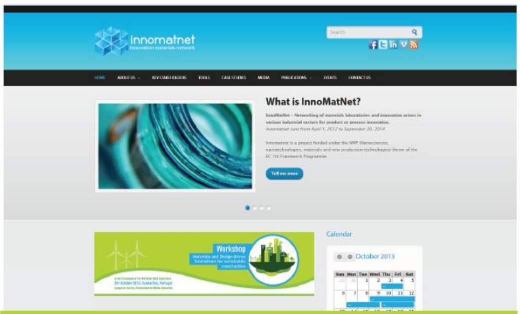

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